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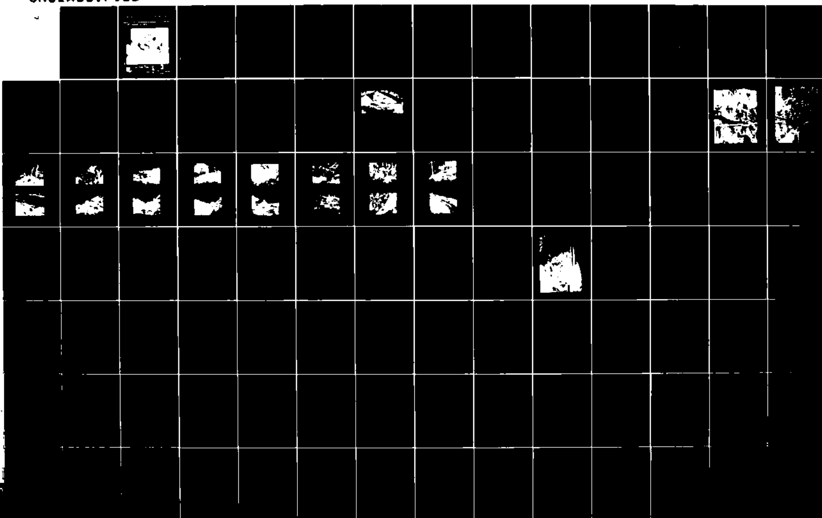

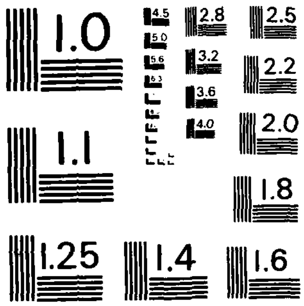

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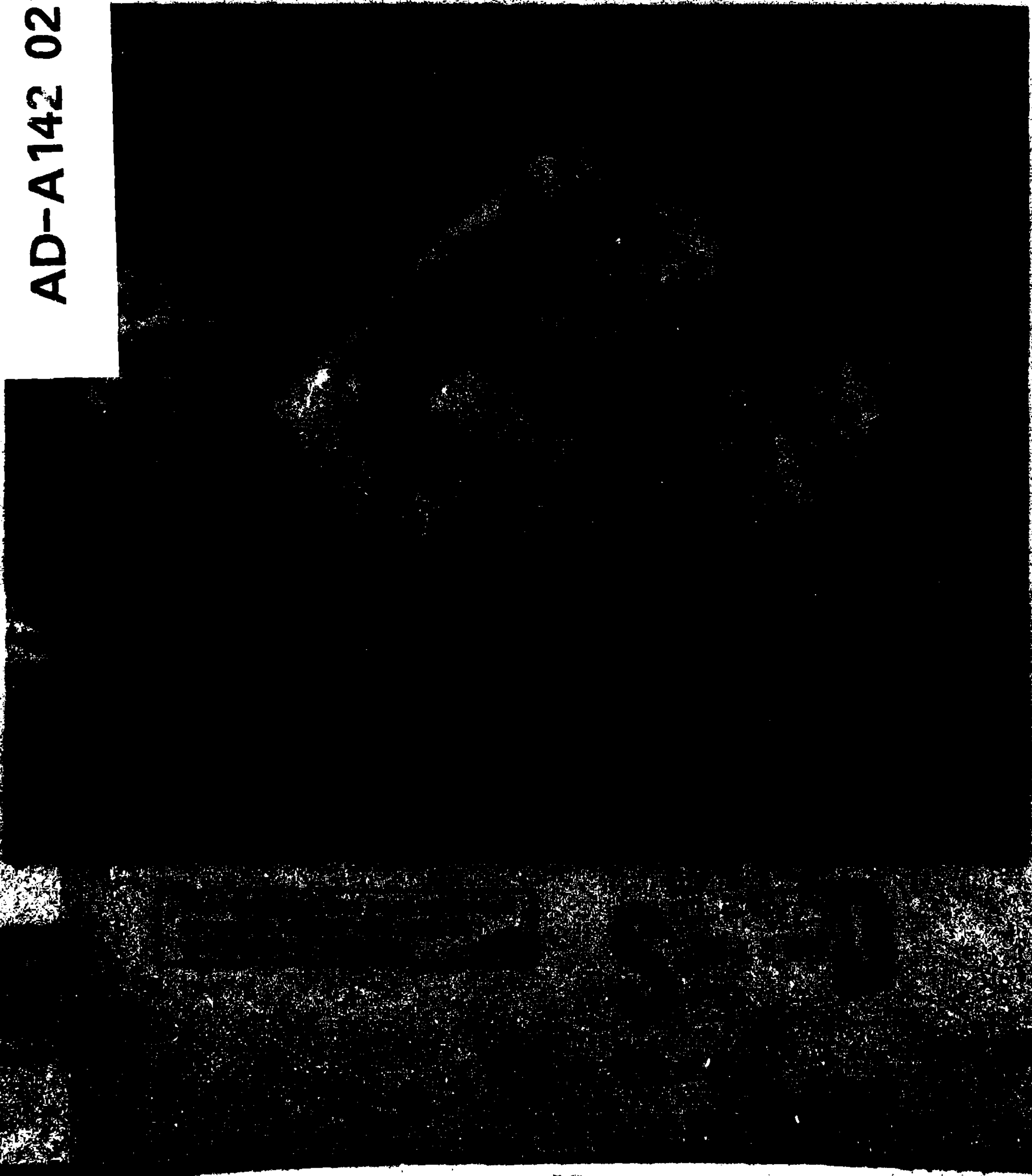
LIBBY DAM AND LAKE KOOCANUSA PROJECT, MONTANA

LEFT BANK SLOPE



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REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER	2. GOVT ACCESSION NO. AD A142 021	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) Libby Dam and Lake Koocanusa Project, Montana Left Bank Slope		5. TYPE OF REPORT & PERIOD COVERED Final
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) Seattle District, Corps of Engineers		8. CONTRACT OR GRANT NUMBER(s) N/A
9. PERFORMING ORGANIZATION NAME AND ADDRESS Seattle District, Corps of Engineers P.O. Box C-3755, ATTN: NPSEN_FM Seattle, WA 98124		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
11. CONTROLLING OFFICE NAME AND ADDRESS Same		12. REPORT DATE April 1984
		13. NUMBER OF PAGES 291 pages + 9 plates
14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office)		15. SECURITY CLASS. (of this report) Unclassified
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

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17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Rock Slope Instrumentation, Slope Stability, Libby Dam, Montana

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Report details the geology and history of the Libby Left Bank Slope instrumentation program, presents plots of instrumental data for the period 1967-1983 and provides a technical evaluation of the present status of the slope.

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SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

LIBBY DAM-LAKE KOOCANUSA PROJECT

LEFT BANK SLOPE

EXECUTIVE SUMMARY

This report presents the geology, history of investigation, details of instrumental monitoring and other data involving the safety of the rock slope at and approximately 2,000 feet upstream from the left abutment of Libby Dam. An analysis of instrumental data from 1972 through 1983 is presented and plots of instrumental data are provided in appendixes.

The slope consists of five major downslope-trending rock ribs whose stability is controlled by geologic structure. A major prehistoric rockslide bounds the upstream end of this slope and Libby Dam abuts into a rock rib at the downstream end. The Left Abutment Rib was undercut for highway construction in 1967. This resulted in partial failure of this rib in 1971; a failure forecast by instruments. Subsequent actions included tendoning of the rock mass of the Left Abutment Rib, construction of a shot-rock buttress at the toe of most of the remaining slope and instrumental monitoring of the entire slope.

The stability analysis, preventive measures taken and instrumentation program installed were studied and approved by the Board of Consultants for Libby Dam and higher authority. During the period since construction, some of the instruments have been abandoned, other instruments have been replaced and plans have been made for further instrument replacement over a period of time. The instrumental array has been an effective tool in monitoring both long term rock mass creep and adjustment, and in predicting ultimate or imminent failure of certain rock masses. The array should be continued and modified as necessary for the life of the project.

Consequences of failure are not possible to accurately predict but would vary from rib to rib depending, in the case of a large mass, on the elevation of the reservoir. The principal danger is potential loss of life to highway travelers in the highway cut adjacent to the left abutment or failure of the upper portions of the upstream rock ribs. A warning system providing for automatic closure of the highway in event of a major failure of the left abutment rib has been emplaced. Wave damage by a large slide from the upstream ribs would probably be confined to project facilities with little flood wave damage expected downstream from the project.

Analysis of data through the end of 1983 indicates continued adjustment of the tendoned rock mass of the Left Abutment Rib, possible minor adjustment low and deep in the rib and some continuing movement of the rock mass above the tendon field. These adjustments do not indicate the slope to be in danger of imminent failure, but reinforce the need for continued monitoring. The extensometer array monitoring the four upstream ribs provides no indication of significant rock mass movement.

ACKNOWLEDGEMENT

This report was prepared by the staff of Foundation and Materials Branch, Engineering Division, U.S. Army Corps of Engineers, Seattle District. Richard W. Galster, Chief, Geology Section, was principal author with the assistance of Kenneth D. Graybeal, Chief, Soils Section. Graphics were contributed by Robert H. Searing, William J. Cox, Robert T. O'Malley, Steven Z. Meyerholtz, and Christine E. Kollen. The work was done under the general supervision of Ralph E. Morrison, Chief, Foundation and Materials Branch, and Richard P. Sellevold, Chief, Engineering Division.

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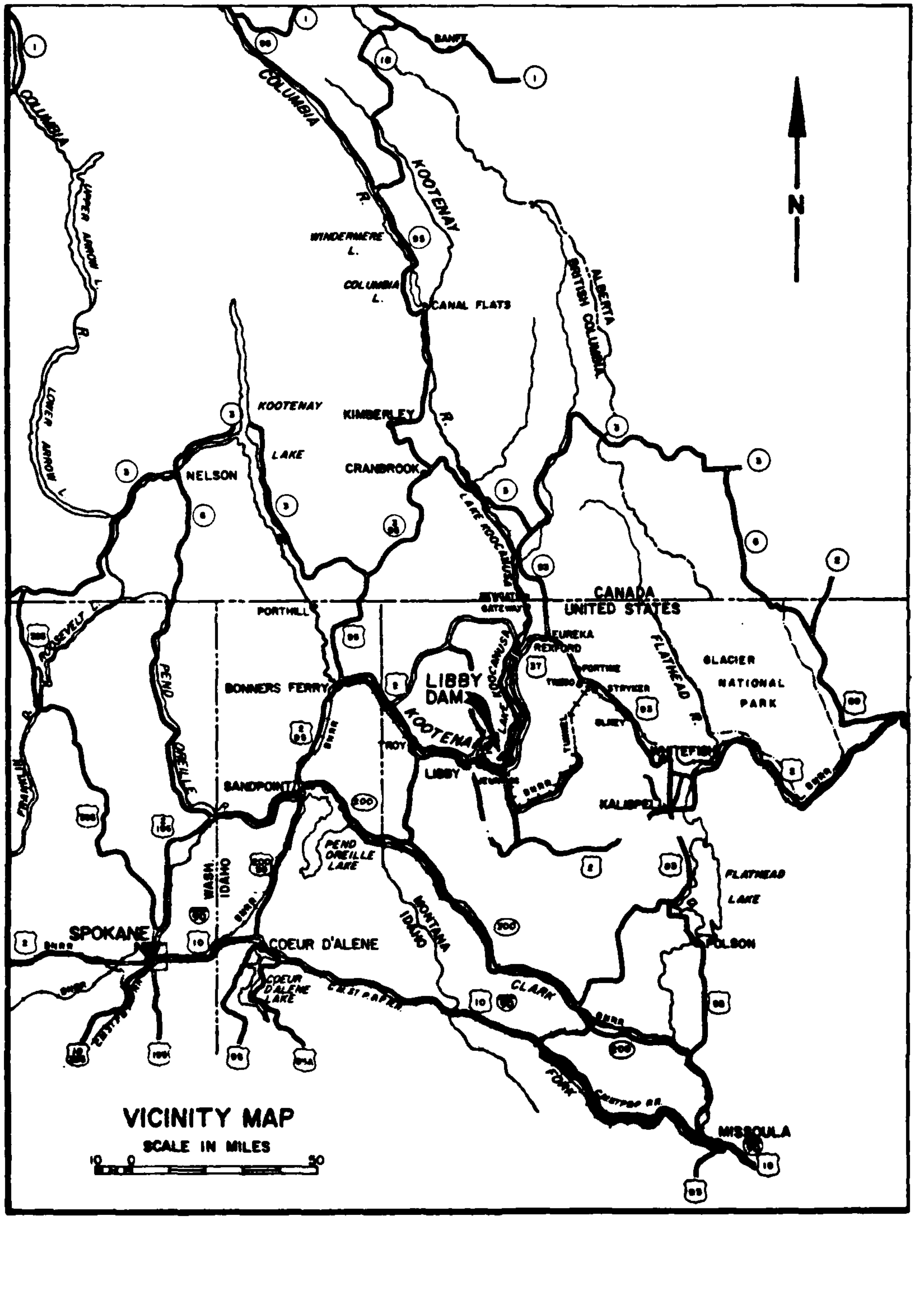
LIBBY DAM-LAKE KOOCANUSA PROJECT
LEFT BANK SLOPE

SECTION 1. INTRODUCTION

1.01 Purpose and Scope. This report presents a comprehensive summary of events and decisions relating to the past, present, and future stability of the Left Bank Slope; the steep, mostly rock slope adjacent to and upstream from the east side of Libby Dam, Kootenai River, Montana. The report presents the geologic setting, a historical review of geologic investigation, instrument types, installation, and monitoring, together with staff, higher authority, and consultant decisions relating to the problem. An analysis of the instrumental data through 1983 is also presented. The purpose of this report is three-fold; to present the summary and analysis for higher authority review, to assess the current condition and comment on possible future actions and to provide a more permanent historic record of actions taken to date (while at least some of the participants with firsthand knowledge of the events are available) for the guidance of future staff. This report is prepared under the authority of Engineering Regulation 1110-2-100, "Periodic Inspection and Continued Evaluation of Completed Civil Works Structures," dated 30 March 1977.

1.02 Description of Project. Libby Dam is on the Kootenai River in northwestern Montana 221.9 river miles (R.M.) upstream from the confluence of the Kootenai River with the Columbia River and 17 miles upstream from the town of Libby, Montana (figure 1.1). The project consists of a multipurpose concrete gravity dam 420 feet high, which impounds a reservoir 90 miles long, backing water 42 miles north into Canada. An onsite powerhouse having an eight unit potential is provided. Final siting was made in 1963. Construction of the dam commenced in April 1967 and was completed in July 1973. The reservoir was raised to a maximum elevation of 2,405 feet in 1972, to 2,415 feet in 1973, and the first normal full pool at elevation 2,459 feet was attained in the summer of 1974.

1.03 Statement of Problem and Background Summary. The Left Bank Slope comprises a segment of the eastern side of the Kootenai Valley from approximately 300 feet downstream from the left abutment of Libby Dam to approximately 3,000 feet upstream. The slope is characterized by a series of rock ribs and troughs trending directly up and downslope yielding somewhat of an irregular "sawtooth" configuration to topographic contours. This configuration is controlled by the pervasive geologic structure. The geologic configuration is such that slope failure could potentially involve any one of these several large joint bounded ribs, resulting in mass-movement of many thousands of cubic yards (c.y.) of material. Potential results of such a failure range from blockage of Montana State Highway (MSH) 37 to creating a dangerous wave on the reservoir in close proximity to the dam. Any oversteepening of the rock ribs through natural erosion or removal of material by artificial means compromises the stability of a portion of the individual rib. The left end of the concrete gravity dam abuts into the most southerly (downstream) of the rock ribs. The positioning of MSH 37 adjacent to the abutment required construction of a high (120 feet) cut in the rock rib adjacent to the abutment, undercutting one large and several smaller wedge-shaped blocks.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LAKE KOOCANUSA
CANADA
UNITED STATES
PORTHILL
EUREKA
REXFORD
GLACIER NATIONAL PARK
BONNERS FERRY
LIBBY DAM
KOOTENAI
TROY
LIBBY
FLATHEAD
KALISPELL
SANDPOINT
PEND OREILLE
PEND OREILLE LAKE
FLATHEAD LAKE
WASH
IDAHO
MONTANA
SPOKANE
COEUR D'ALENE
COEUR D'ALENE LAKE
POLSON
CLARK FORK
MISSOULA
VICINITY MAP
SCALE IN MILES
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FIGURE 1.1

The cut was instrumented prior to construction and one of the instruments produced a classic record of ultimate failure over the following 3-1/2 years. Failure of a large wedge (approximately 60,000 c.y.) occurred on 31 January 1971 and was followed by a concentrated program of geologic investigation and analyses, tendoning of the rock mass adjacent to the upstream side of the slide, an extensive slope instrumentation program, and ultimately, construction of a shot-rock fill buttress at the toe of four of the rock ribs to increase stability in the area influenced by a fluctuating reservoir. Later additions were made to the instrument and tendon programs. The instrumentation system, installed after the slide in 1971 was intended to have a 10-year life which has now been attained. The instrumental data does not always yield clear information and is subject to different interpretation for a variety of reasons. The Seattle District reported results of the instrumental data to a Board of Consultants and Special Consultants, and higher authority at frequent intervals until May 1975 after which the consultants were discharged. The final admonition of the Board was to continue the instrumentation program for an indefinate period. Subsequently the instrumentation system and data have been subject to frequent inspection by the District staff and the results discussed in general terms in subsequent periodic inspections of the project. The staff has reacted on several occasions to the stimulus of instrumental data, the most notable late in 1975 and early in 1976 which resulted in additional tendon installation and instrumentation. Early in 1982, the District staff again reacted to potential meaningful instrumental data. At this time the District felt that a comprehensive review of the history and status of the whole Left Bank Slope problem would be appropriate with the following questions in mind:

- How did the District reach its present position with respect to stability of the Left Bank Slope?

- Is the instrumentation system still appropriate and viable?

- What is the most appropriate interpretation of the instrumental data and what may be concluded from it?

- Should the District be taking additional actions with respect to the stability of the slope and its monitoring?

The District has long ago committed itself to long-term monitoring of the slope as an item critical to project safety. Thus, the question of whether or not a monitoring system should be maintained is not under consideration in this report.

SECTION 2. GEOLOGY

2.01 Geologic Setting.

a. The project is in northwestern Montana within the Northern Rocky Mountains. The region is characterized by both high, rugged, and more subdued mountain ranges which trend north to north-northwest, separated by relatively narrow, linear valleys, all controlled by bedrock structure. General relief in the region is on the order of 5,000 feet. The region is underlain by a thick series of Precambrian metasediments known as the Belt Series (or Supergroup) which consist of argillite, quartzite, metasandstone, and limestone of variable purity. These rocks have been folded and faulted, generally in northwestward trends, during their long history and are characterized by a well-developed joint system. Most of the geologic structure resulted from eastward crustal compression during the late Cretaceous and early Tertiary periods. Locally, igneous intrusions have invaded the rocks, causing changes by contact metamorphism and hydrothermal alteration together with superposition of additional joint patterns. Much of the region was periodically glaciated during the Pleistocene by continental ice moving south from Canada or local valley glaciers from the higher ranges. Thus, much of the region is mantled by a variety of glacial deposits varying from a thin mantle of drift on higher slopes and ridges to deep fills of lake silts, till, and outwash sands and gravels several hundred feet thick in some valleys. While the present master drainage system is influenced by rock structure, it has, along with secondary drainage, been modified by the effects of glaciation.

b. The Kootenai River enters the United States on the floor of the Rocky Mountain Trench, a prominant northerly trending valley which separates the more rugged main (thrust) ranges of the Rockies on the east from the subdued (folded) ranges to the west. Ten miles south of the 49th Parallel the river leaves the trench and has cut a south-trending, steep-sided valley for 60 miles at an acute angle to the geologic structure. The valley separates the Purcell Mountains on the west from the Salish Range on the east. It is near the lower end of this valley segment that Libby Dam has been constructed. A short distance downstream from the dam the river turns abruptly westward, cutting across the general trend of the geologic structure to the Purcell Trench where it turns north and again enters Canada.

2.02 Site Geology.

a. This section of the Kootenai Valley in the vicinity of the dam trends about S35W. The left (east) valley side is steep and locally precipitous and consists of a series of bare to variably forested, downslope trending rock ribs separated by openly forested troughs partly filled with glacial drift and talus. The valley side rises from elevation 2,130 feet at the floor to about 3,200 feet at the ridge crest. The ridge forms a high valley wall for about 1/2 mile. The dam is located at the downstream end of this segment. A rock debris pile and slide scar from a major postglacial rock slide is at the upstream end of this segment; the rock debris pile now concealed beneath minimum reservoir level. The slide trough has been locally filled by an embankment for MSH 37. Prior to construction, the slide scar and debris pile were very evident and formed an important constriction of the valley called Kootenai Narrows (plate 1). The valley floor prior to construction was relatively flat at elevation 2,130 feet with the main river channel against the toe of the left (east) valley side and a high-water channel near the toe of the right (west) valley side. The valley floor was underlain by 30 to 70 feet of alluvial sand, gravel, and boulders.

b. Bedrock at the dam represents the transition zone between the Ravalli and overlying Piegan Groups of the Precambrian Belt Supergroup. High on the east (left) abutment and comprising essentially all of the Left Bank Slope are the moderately hard to hard, siliceous, greenish-gray argillites of the uppermost Ravalli (Koocanusa Formation), locally displaying thin stringers of quartzite or metasandstone. Much of the lower part of the left abutment and part of the rock beneath original valley alluvium varies from buff, calcareous and noncalcareous, moderately hard argillite with two prominent limestone beds characteristic of the lower Piegan. All the bedrock is sound, competent, and thinly- to medium-bedded.

c. A well-developed fracture system is present, which is consistent with regional joint patterns. The principal joint sets are tectonic in origin while others have resulted from rebound or other near-surface phenomena. The fracture system is divided into the following sets:

(1) Bedding joints and bedding faults which strike N30W and dip 40 to 45 degrees west toward the valley form moderate downstream facing slopes on the left side of the valley.

(2) A conjugate set of generally east-west striking shear joints, which exhibits strong individuals striking from due east-west to N70E and N70W and dip at high angle (60 to 90 degrees) to the north or south. These joints commonly form strong upstream facing scarps and, with bedding joints, form a multitude of small and large wedges, some of which daylight on the left valley side.

(3) North-south striking "relaxation" joints may strike from N10W to N20E but generally dip 50 to 80 degrees east (into the left abutment). These joints truncate the rock ribs on the left valley side commonly forming overhanging scarps.

(4) Transverse tension joints which strike northeast and dip at moderate to high angles to the southeast, often form overhanging scarps on the left abutment.

(5) Tension joints, which strike nearly the same as bedding but dip nearly at right angles to the bedding, may be analogous to fracture cleavage developed during folding.

(6) Low angle rebound joints which have random strikes.

(7) Miscellaneous local fractures which are produced during rebound by adjustment of blocks bounded by the principal joints.

Of these sets, the bedding, east-west and north-south are the most important in the development of the topographic form of the valley walls and in the stability of large rock masses. In and above the left abutment, several prominent bedding faults are present. These faults, which are continuous from the abutment into or adjacent to the foundation, are frequently characterized by clay gouge and rock fragments. These bedding faults were originally generated during the generally gentle folding of the thick section of metasedimentary rocks late in the Cretaceous. The surface traces of these faults are seen for a considerable distance upslope. A reference bedding fault is noted as the Dirty Shame (DS) Bedding Fault, the trace of which passes just upstream from the heel of the dam and dips beneath the dam. Successive stratigraphically higher bedding faults are known as the DS+50, the DS+80, and the DS+122. (The designation refers to the approximate vertical difference in feet above the DS.) Major bedding faults stratigraphically below the DS are, for the most part, designated by MSH 37 station (909, 927, etc.). These all lie upstream from the left abutment. Several generations of movement are noted on the bedding faults and on east-west and north-south joints which, together with the bedding faults, break the rock mass into discrete blocks. This is especially critical on the Left Bank Slope where the structural orientation provides the potential for gravity wedge failure. In addition, certain joints and bedding faults or planes were found to be open to considerable depths in the foundation and especially behind the abutments. The openness of these features is believed due to stress release from valley cutting and from the deglaciation. The last movement based on slickensides and pinch and swell features on the DS Bedding Fault is interpreted to be on the order of 2 feet downslope. Compression at the toe of the left abutment appears to have caused movement along the preexisting north-south joint set (Ramp joint). In addition to the bedding faults, the series of east-west striking, generally planar shear joints, also trend up and down slope. In the left abutment area these joints are designated by letters A through F. Elsewhere on the Left Bank Slope these joints are not as well recognized, but those known or assumed are letter designated. The third important joint set is the north-south striking tension joint set. Individual joints of this set are not designated by name or letter as they tend to be discontinuous. It is the combination of these three joint sets which create the infinite size and variety of wedge-shaped blocks within the rock mass making up the slope. Structural troughs formed by the intersection of bedding faults and east-west joints plunge from 25 to nearly 40 degrees toward the valley and the north-south joints provide planes of easy detachment. Thus the stability of any portion of slope is a function of the steepness of the joint trough, in relation to effective friction on the joint or fault, and in the clay gouge material, the weight of the discrete rock wedge involved, and effective buttressing or the stabilizing measures present. Any undercutting of masses by natural erosion or artificial means ultimately results in failure of a rock wedge and the geologic record exhibits a number of such failures on this slope. These include the postglacial, prehistoric Kootenai Narrows Slide and its companion rock slide just downstream. Elsewhere on the slope the slide troughs are partly filled with glacial debris and talus attesting to their pre-last-glacial origin. The result is a series of five rock ribs, four of which have major topographic expression from top to bottom of the slope and the remaining one which "hangs" high on the slope or, at least, is subdued lower down. These ribs and their actual or hypothetical bounding faults are shown on plate 2.

2.04 Kootenai Narrows Slide. A unique constriction in the Kootenai Valley was evident at R.M. 219.5 about 1/2-mile upstream from Libby Dam prior to the raising of Lake Koocanusa (plate 1). The morphology of the feature, its constituent materials, and the geologic structure and topography of the adjacent left valley wall led to the conclusion at an early stage of geological investigation that the feature originated as a major rock slide. The feature consists of a debris pile of rock blocks and rubble locally mixed with gravel and partly mantled by silt and sand. The original shape of the rubble pile fanned westward, and the prereservoir channel was close against the toe of the left (east) valley wall, presumably the low point in the rubble pile. The high point of the rubble pile is at elevation 2,220 feet near the toe of the right valley wall. The base of the rubble pile is about elevation 2,075 feet beneath the prereservoir channel. The trough from where the rubble originated rises from elevation 2,150 feet at the toe to 3,300 feet at the top in a distance of about 2,000 feet. The trough was formed by a major bedding fault and an east-west fault with the plunge of the intersection estimated at 29 degrees toward the valley. Depending on the assumption of preslide topography, the volume of the slide is estimated between 1.75 and 2.5 million c.y. The configuration of the rubble pile and its position in the valley indicates that it was a high velocity slide. The slide velocity has been estimated as between 62 feet/second and 155 feet/second. The date of the event is not certain. It is clearly postglacial and prehistoric. The river was essentially at its present grade so that the event probably occurred not more than a few hundred years ago. Investigations at the toe of the trough show that the trough was not entirely undercut by the river and that failure required shearing through the rock mass or release along preexisting joint sets. It is possible that the failure was timed by a seismic event. This feature has provided an excellent field laboratory to study the future potential effects of Left Bank Slope failures.

SECTION 3. HISTORICAL REVIEW

3.01 General. This section reviews the significant investigations, events, recommendations, and decisions involving the Left Bank Slope from 1961 through 1983. This includes summaries of appropriate discussions at Board of Consultants meetings, design memoranda, consultant reports, and other data in the District files.

3.02 Early Investigations. Initial investigations of the Left Bank Slope began during the summer of 1961 with the first vertical core boring from high on the present left abutment and a general reconnoitering of the left abutment. The rock slide at Kootenai Narrows was identified and its origin recognized, but the investigative emphasis remained on abutment and foundation bedrock configuration at the R.M. 219 and other proposed axes. During March of 1962 a geologic map was made of the Left Bank Slope by plane table and alidade methods, but the available 1 inch equals 50 feet topographic base proved to be inadequate. The study did, however, identify the geometry and structural fabric of the slope and recognize the concept of past and future wedge failure problems. In order to properly evaluate the left abutment area, a detailed topographic and geologic map was made at a scale of 1 inch equals 20 feet, again by plane table methods. The tree cover was too extensive to accomplish an adequate topographic base by photogrammetric methods. This map, together with a series of core borings and three adits, completed during the 1962 and 1963 field seasons, defined the geometry and characteristics of the left abutment for the dam. Because concentration of effort was focused on the abutment, less attention was given to the details of the geology upstream on the Left Bank Slope. The geologic details of the left abutment may be found in the Libby Dam Foundation Report.

3.03 Siting, Design and Construction Considerations.

a. Following ratification of the Columbia River Treaty by the United States in March 1961, the District began serious consideration of the reach of the Kootenai River between R.M. 215.5 (mouth of the Fisher River) and R.M. 222. Fifteen potential dam locations were studied to various extents, mostly by topographic profile. Of these, four were studied in detail by developing geological information and project layouts. The costs and position of highway relocation were not considered in the final site selection at R.M. 219. The selection was reviewed by representatives of the Division Engineer, Chief of Engineers, and Edwin E. Burwell, Consulting Geologist (former Chief Geologist, Corps of Engineers). An important element in the construction sequencing was the requirement of the Columbia River Treaty that the reservoir be raised within 7 years after commencement of construction. This required tight construction sequencing and permitted no delays in construction work.

b. The rock cut adjacent to the left abutment was designed as part of the relocation of MSH 37, Unit 3A. The inclusion of a visitors' area on the left abutment required placement of acceleration/deceleration lanes to provide access. This increased the highway design width to 60 feet and moved the alinement further into the hill (Design Memo (DM) 9, Supplement (Supp) 11, March 1966) requiring a rock cut to heights of 150 feet. The design recognized the importance of the geologic structure and indicated that some fallout might result though major fallout was not anticipated. The design called for 1/4 horizontal to 1 vertical cut slopes but indicated that flattening of rock cut slopes might locally be required and that the amount of slope treatment required could not be logically determined until excavation was in progress.

c. During the first meeting of the Board of Consultants1/ in November 1965 the District indicated awareness of the danger and its intention to avoid undercutting rock blocks bounded on the upstream side by clay filled bedding faults. The District further indicated that some rock anchoring would be required and noted its intent to install "rock noise" monitors in the area. (This was not put into effect until the abortive system placed in 1971.) However, the Boards' geologist member (Thompson) questioned the adequacy of investigation with respect to slide potential upstream from the left abutment. He suggested additional investigation and model testing to determine possible effects of a slide on the dam.

d. In April 1966, alternative plans for relocation of MSH 37 around the dam were considered. These included moving the alinement riverward by redesign and/or resiting of the left abutment parking lot; or crossing the area at elevations 300 to 500 feet higher where topography is less steep. The Montana Highway Department (MHD) was opposed to any major change in alinement (2nd indorsement to Supp. 11, DM 9) unless further studies indicated "insurmountable difficulties" for routing across the Left Bank Slope. However, as a result of a field conference with NPS/NPD in July 1966, a compromise plan was reached. This plan did move the alinement riverward which reduced the height of the cut adjacent to the left abutment from about 150 feet to 125 feet. This plan included bridges and retaining walls to span or buttress appropriate areas along the alinement across the Left Bank Slope. During the July field conference the District thoroughly discussed the problems, indicating the possibility of a 70,000 c.y. rock slide in the cut adjacent to the dam and proposed prestressed rods or cables together with rock bolts be designed for this section. The Division and MHD believed that the slide risk, both in the left abutment area cut and upstream, was not serious and could be adequately handled by providing for removal of rock in problem areas or by bolt or cable anchoring of possible unstable rock. In August 1967, the District Geologist continued to express concern about the ultimate stability of the rock wedge especially under winter and spring thaw conditions when hydrostatic pressures and possible expansion of joints could adversely affect stability.

3.04 Slope Instrumentation and Construction of MSH 37 Cut. The cut adjacent to the left abutment was included as part of the dam construction contract. As part of this contract, seven multiple-position borehole extensometers

1/Original Libby Dam Board of Consultants consisted of John Alexander (Civil Engineer), Jerome Raphael (Structural Engineer), and Thomas Thompson (Geologist).

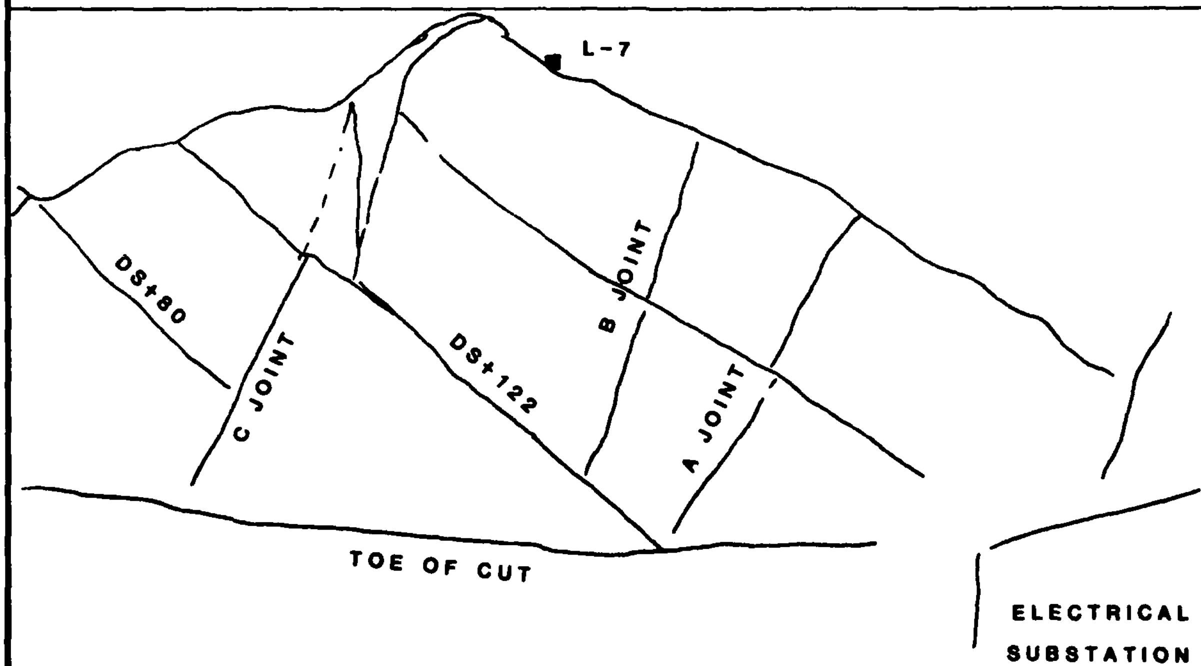
(MPBX) were programmed for installation, five adjacent to the future keyway for the left abutment and two above the MSH 37 cut. Other than mobilization, clearing, and access road construction, the installation of extensometers L-6 and L-7 above the cut were the first items of work and the instruments were activated by 1 June 1967 just prior to beginning of cut construction (plate 4). Fifty-seven rock bolts are reported to have been installed above the cut prior to excavation. The cut was excavated in segments and lifts outside of a presplit back slope. On 26 June 1967, when the cut had been partly excavated and the muck partly removed, a small (5,000 c.y.) wedge of rock bounded by the DS+122 and a splay of the C Joint failed and moved into the muck pile. The wedge was removed and the cut carried to grade without further incident (figure 3.1, plate 4). Blasting was completed about 15 August. During the excavation period, MPBX L-6 showed about 0.13-inch borehole extension (i.e. downslope movement) with about half of the movement taking place across the DS Bedding Fault (figure 3.2). During the same period L-7 registered a total of 0.84-inch extension of which only 0.15 inch occurred across the DS+122; the bulk of the movement occurred in the outboard 50 feet of the boring along near surface bedding and vertical east-west joints (figure 3.3).

3.05 <u>Monitoring and Actions 1967-1971</u>.

a. Upon completion of the MSH 37 cut adjacent to the dam attention was largely directed to preparation of the left abutment keyway and foundation preparation under the first stage diversion. Inaccessibility to instruments L-6 and L-7 above the cut made reading impossible from late November 1967 until early February 1968 when long cables were installed from the instrument heads to the toe of the cut to facilitate readout. Continued monitoring showed that beginning in February 1968 extension occurred in the zone between the head and first anchor of L-7 (figure 3.3). Extension on successively deeper anchors was noted as the year progressed, but the extension was a slow, nonaccelerating creep. This suggested some continued expansion of the rock mass adjacent to the cut but no creep on the DS+122 Bedding Fault. L-6 exhibited no movement during this period.

b. During the Board of Consultants meeting in Libby on 1-2 May 1968, movements registered by instruments adjacent to the left abutment keyway were discussed, but movement was believed to be rebound due to excavation. Attention was focused on the left abutment excavation. The question of the cut face was neither asked of nor addressed by the Board, though some surprise was expressed by the Board geologist with respect to magnitude of movement.

c. About 1 February 1969, L-7 indicated that the outboard 100 feet of the rock mass (between the head and anchor 2) began a slight acceleration of valleyward creep (figure 3.3). About 1 April, a similar event began in the mass between anchors 2 and 3 which monitored a series of North-South joints and an "open" east-west joint. The onset of this latter creep was coincidental with a felt earthquake in the area. This event was Richter Magnitude 4.7 and centered in the Big Arm area of Flathead Lake, 64 miles south-southeast of the site. It was felt as Modified Mercalli (MM) Intensity VII in the epicentral area and as MM Intensities I-III in the site area. On 9-10 April 1969, the



COMPOSITE PHOTOGRAPH OF MSH 37 CUT ADJACENT TO LEFT ABUTMENT, WINTER 1968.

FIGURE 3.1

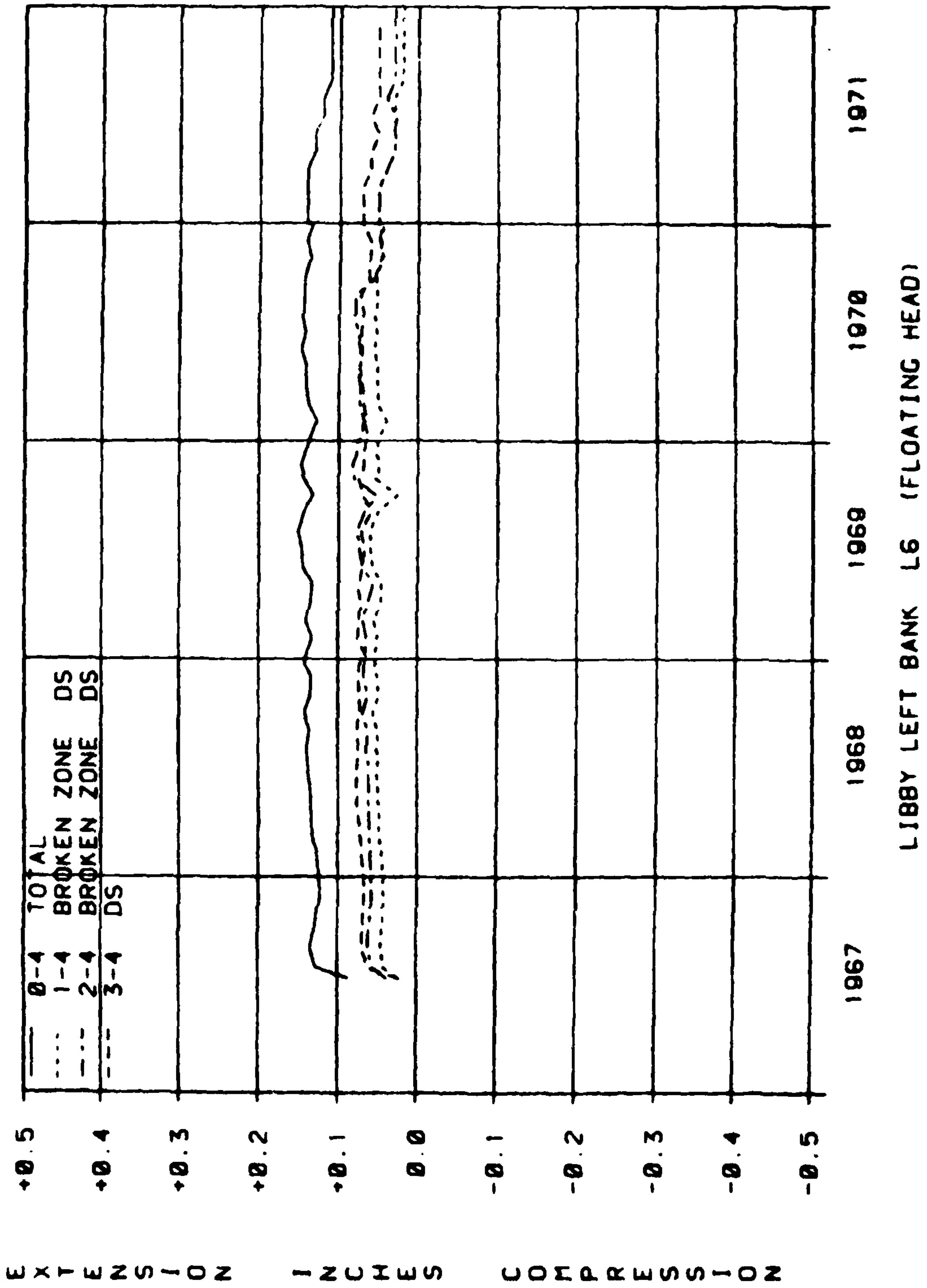

0-4 TOTAL
1-4 BROKEN ZONE DS
2-4 BROKEN ZONE DS
3-4 DS
1967
1968
1969
1970
1971
LIBBY LEFT BANK L6 (FLOATING HEAD)
+0.5
+0.4
+0.3
+0.2
+0.1
0.0
-0.1
-0.2
-0.3
-0.4
-0.5
EXTENSION INCHES COMPRESSION

FIGURE 3.2

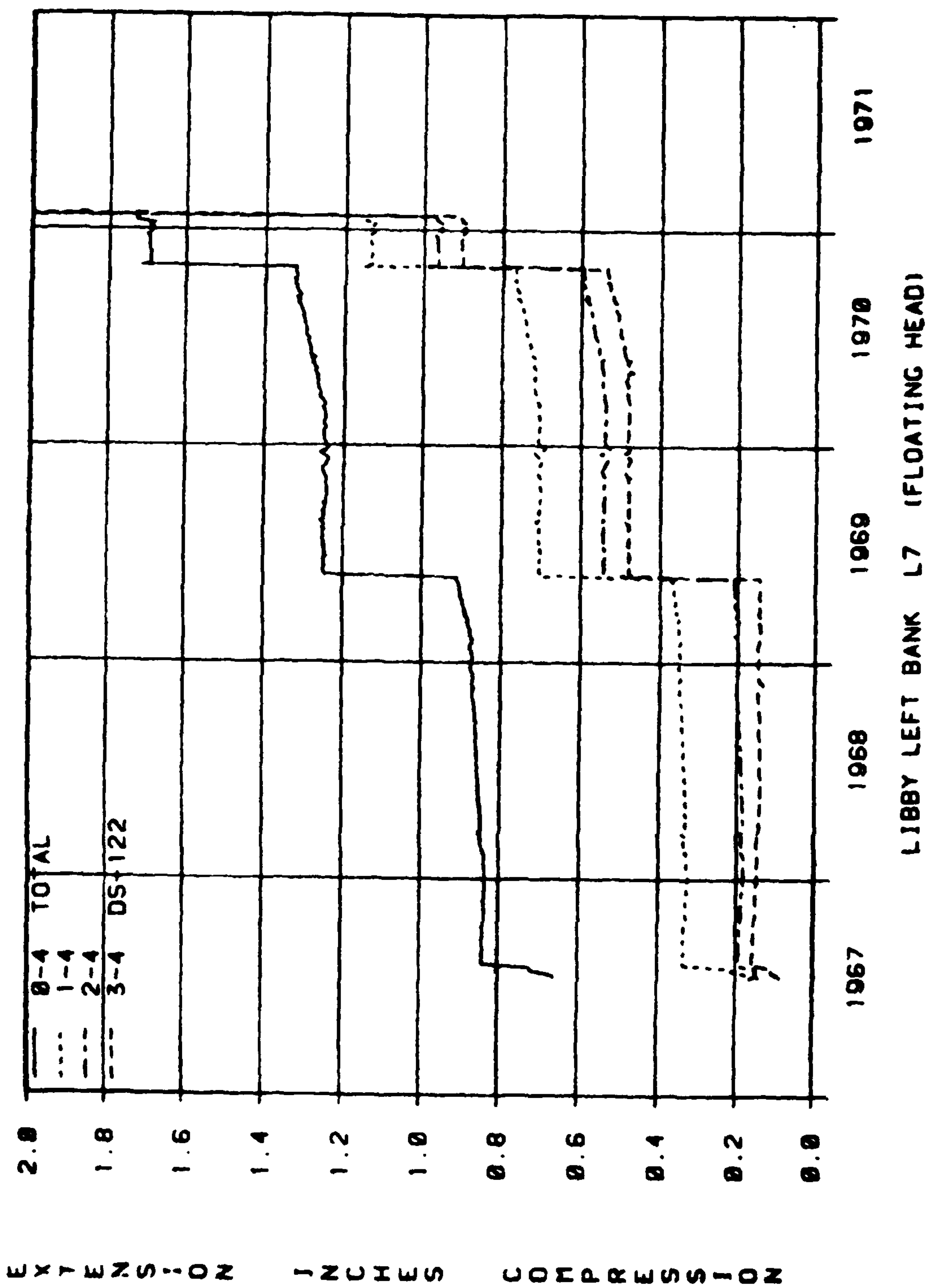

0-4 TOTAL
1-4
2-4
3-4 DS-122
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
EXTENSION INCHES COMPRESSION
1967
1968
1969
1970
1971
LIBBY LEFT BANK L7 (FLOATING HEAD)

FIGURE 3.3

Board of Consultants were apprised of these conditions. The District identified two possible wedge blocks which had been undercut by the excavation, but the Board expressed no concern for stability. They did, however, agree with the District that plaster cast "witness bars" shall be installed on the cut face. Acceleration of creep continued. Between 23-26 May 1969, 0.35 inch of rapid extension was recorded between anchors 3 and 4 of L-7. This movement could only be interpreted as downslope movement of a wedge bounded by the DS+122 on the upstream and an unknown east-west joint downstream. The District geology staff interpreted this event as a step in the progressive failure of the wedge. The resident engineer proposed an annunciator system across the cut face, a system which was emplaced shortly thereafter with warning lights in the nearby instrument laboratory to indicate movement events.

d. When the Board of Consultants met on 29-31 July 1969, the concern was for control of concrete cracking. None of the District nor OCE geology staff were present. As an aside, however, the Board geologist indicated that a slide above the MSH 37 cut might be "imminent," suggesting that "measures be taken" to "stabilize the entire cut area which, if not stabilized, could lead to a disastrous failure that could destroy the screening plant, cooling plant and other installations . . . vital to the construction of the dam." High tensioned rock anchors were recommended for installation. The Board also recommended that the highway, upstream from the dam, be placed on an embankment laid against the valley side suggesting that the "bridge" concept was hazardous. Further instrumentation of the slope was also recommended. This resulted in the first recorded discussion of the matter between the Board, the District (sans geology staff), and higher authority. The Board geologist was adamant that action be taken and considered a doweling program proposed by the District to be inadequate. A model study of high velocity rock slide generated waves was also recommended. The Division geologist did not share his concern, however, and no decision was made before the Board moved to other topics.

e. In August 1969, after a slope inspection with OCE and NPD geologists, the District proposed a program of installing 10 rock bolts and 10 dowels to improve the factor of safety in the rock mass downstream from the trace of the DS+122. Higher authority did not concur with the proposal having the opinion that the rock slide hazard was minimal, that the proposed action would have minimal influence on the stability of the rock mass, that the instrumentation would give adequate warning of imminent failure during the construction period, and that the mass could be supported or removed prior to opening the road to the public. Discussion between the District, the Division, and Office, Chief of Engineers was carried on by mail until April 1970. During this time L-7 showed no movement of the rock mass.

f. Late in March 1970, L-7 again began to indicate valleyward creep of the rock mass outboard of the DS+122 (figure 3.3). Some acceleration of this creep began in May and continued throughout the summer. The District forecast that a second step or failure would occur and that the magnitude of the movement was already greater than the precurser to the first step. When the Board of Consultants met at Libby on 29-30 July 1970, they were presented not only with a revised design of this section of the highway encompassing large amounts of embankment along the Left Bank Slope but were treated to a comprehensive dissertation of reservoir slide potential in general. Rerouting of MSH 37 through a tunnel deep behind the Left Bank Slope or on the higher "Dunn Creek" route was further discussed by the District and the Board. The Board recommended additional study on the three major highway alternate routing concepts; bridge spans, embankment, tunnel and high route, but definitely recommended against founding bridge spans on the rock ribs of the Left Bank Slope. Analysis and discussion of these alternatives by NPS continued almost to the time of MSH-37 (3B-1) contract bid opening in August 1970. The embankment scheme, having the lowest risk factor and being the most acceptable scheme, was ultimately chosen. The contract for construction of this portion of the highway (3B-1) was not awarded, however, until late October 1970. By December, foundation excavation in an old slide trough upstream from the 914 rock rib exposed bedding and east-west faults, which further concerned the District geology staff. A systematic mapping program was initiated during excavation in order to provide data for future stability analysis.

g. Early in October 1970 the accelerating movement registered by L-7 leveled off followed, between 30 October and 2 November, by a sudden jump of 0.37 inch on the DS+122. A minor local earthquake was recorded at the Libby Dam Seismic Station, 3 miles up valley on 31 October. Thus after 7 months of accelerating creep the second step failure occurred and was of the same order of magnitude as the first step failure had been after a much longer period of total creep and a much shorter period of acceleration. This suggested that about the same amount of movement was required to develop sufficient friction to arrest the wedge. The District immediately informed higher authority informally and began to prepare a more formal notification. The letter to the Division Engineer, dated 8 January 1971, clearly stated, "the past record of activity in terms of strain build-up followed by sudden movement indicates . . . eventual failure of the rock wedge bounded by the DS+122 Joint and one or more east-west trending downstream joints." The letter was forwarded to OCE 10 days later.

h. One further problem became evident at this juncture. Through some quirk in the data processing program, the wire elongation factor required for computation of motion in the type of wire extensometer employed had been entered twice. Hand computations, performed early in the program history when little movement had occurred, had not revealed the problem. As a result the movements indicated by L-7 were, in reality, only about half of what they were thought to be. Not yet realizing this, the District was concerned that the instrument was reaching its limit and that one or more of the extensometer wires might part. The contractor was requested to reset the instrument. This was accomplished on 22 January after L-7 had shown about an additional 0.02-inch jump on the DS+122 about mid-January. The question of wire elongation was crystalized at this time as the instrument was found not to be approaching its range limit as suspected. This changed the magnitude of the recorded strain but not the shape of the strain curve.

3.06 Slide of 31 January 1971.

a. At 0604 mountain standard time, Sunday, 31 January 1971, a major failure of the slope occurred. Construction was shut down for the winter at this time and only two persons were at the construction site; a guard in the guardhouse on the right bank and a maintenance man who was responsible for keeping pumping capacity current within the second stage cofferdam enclosure. The lower 250 feet of the wedge bounded by the DS+122 and the A Joint broke away from a north-south joint at the 2,700-foot ground elevation and moved downslope. The basal apex of the wedge moved probably about 10 feet into the roadway and stopped. Thereupon the lower 80 feet of the wedge began to break apart along existing joints and fell into the uncompleted roadway, rapidly building a pile of rock debris across the roadway and toward the area of the excavated abutment keyway, destroying the contractor's main electrical substation and damaging the aggregate refrigeration plant and the concrete/instrumentation laboratory building. The upslope 170 feet of the wedge stayed relatively intact, moving downslope about 20 feet until restrained by the debris pile generated by the disintegrated lower part. The entire event was registered at the Libby Dam Seismic Station, 4 miles upvalley for 45 seconds, of which the final 16 seconds registered late slide tumbling of blocks into the roadway (figures 3.4 and 3.5, plate 5). The volume involved in the slide was calculated at 60,000 c.y. leaving approximately 20,000 c.y. of the wedge unsupported in the upper portion of the trough above elevation 2,700 feet.

b. The first person to arrive at the scene about 0630 was R.D. Bush, Chief of the Libby Dam Resident Office Instrumentation Section. Bush had meant to be there earlier to read extensometers L-6 and L-7 from the toe of the cut prior to a shower of minor rockfall which characterized the cut slope during morning thawing. He had fortunately overslept. With the loss of site power, the guard busy trying to notify authorities, and the maintenance man trying to get emergency generators started, Bush alone investigated the debris pile adjacent to his instrument lab with a flashlight during the predawn period. He was shortly joined by other members of the residency and later contractor staff. The District Engineer was officially notified by TWX at 1305 hours, 31 January. Principal damage, other than the electric substation, was to the contractor's refrigeration plant and related screening and waterline facilities. The left support for the upstream of two strings of "starlights," which spanned the valley illuminating the construction site, was on the moved block and the starlight string dropped to cut through the refrigeration plant roof (figure 3.5). The instrumentation/concrete field laboratory building suffered minor damage. As a quirk, a small rock broke a window in the instrument laboratory and sliced a hole through a seismogram hanging to dry after processing. Two Corps of Engineers vehicles also suffered minor damage.

3.07 Postslide Actions.

a. The impact of the slide was far reaching. In addition to the obvious problem of slide removal and stabilization of additional areas above the left abutment, the construction schedule for both the dam and MSH 37, Unit 3B(1) was impacted. Spring 1971 concrete placement was delayed. Not only did the

Slide of 31 January 1971 Aerial Oblique FIGURE 3.4

Slide of 31 January 1971 Vertical Aerial FIGURE 3.5

3.6a Aerial view down crest of Left Abutment Rib to slide rubble pile and dam under construction. Note damage to refrigeration plant.

3.6b Aerial view downstream showing slide rubble pile, damage to refrigeration plant and partly constructed dam.

FIGURE 3.6

3.7a View upstream of slide rubble pile showing damage to transformer station and refrigeration plant. Instrumentation/Concrete Laboratory left foreground.

3.7b View upstream to large blocks in rubble pile.

FIGURE 3.7

3.8a View downstream to rubble pile showing damage to refrigeration plant.

3.8b View upstream along toe of rubble pile showing damage to refrigeration plant and aggregate cooling facilities.

FIGURE 3.8

3.9a View of damage to Government vehicles parked in front of Instrumentation/Concrete Laboratory building.

3.9b View upstream to rubble pile showing damage to Instrumentation/Concrete Laboratory buildi ıg.

FIGURE 3.9

3.10a View of large blocks at upstream edge of rubble pile.

3.10b View downstream to rubble pile.

FIGURE 3.10

3.11a View down slide along surface of the Dirty Shame +122 Bedding Fault to rubble pile. Refrigeration plant on right, aggregate cooling facility right center, uncompleted dam upper right.

3.11b View upslope to face of slide (moved block) from surface of rubble pile.

FIGURE 3.11

3.12a View downstream of pullaway at head of moved block.

3.12b View upstream of pullaway at head of moved block.

FIGURE 3.12

3.13a View upstream of pullaway at head of moved block.
Note north-south joints dipping into slope.

3.13b View downstream showing upstream portion of pullaway
at head of moved block.

FIGURE 3.13

slide damage contractor aggregate preparation facilities, but discovery of materials in the troughs upstream which required foundation excavation for the highway and concern for the stability of the remaining rock ribs in the Left Bank Slope. Any slippage in the closure of the dam and a partial pool raise in the spring of 1972 would be in violation of the Columbia River Treaty with Canada. Immediate actions included investigation by District personnel; a team from Engineering and Construction Divisions and Libby Residency. This investigation included the Division Geologist and the Corps of Engineers Chief Geologist. Within a few weeks the dam contract had been modified for removal of 80,000 c.y. of slide material, including material remaining in the DS+122/A Joint wedge upslope. The contract was further modified to haul 137,000 c.y. of concrete aggregate to stockpile downstream from the dam so concrete placement could continue and the highway work progress without the encumbrance of the dam contractor's aggregate conveyor. Conceptual work on placement of posttensioned cables (generally referred to as prestressing) to stabilize the rock mass immediately upstream from the slide mass had begun. Exploration and geologic mapping were underway. On 1-2 March 1971, representatives of OCE, NPD, and the District held a special meeting with consultants Wendell Johnson, Robert Nesbitt, and Thomas Thompson (of the Board of Consultants) at Libby to review ongoing and proposed actions. The group recommended actions both above the left abutment and over the entire Left Bank Slope which included exploration, instrumentation, drainage, and stabilization by tendoning. A comprehensive instrumentation program was to be developed by the District. The consultants further noted the necessity of careful monitoring of potential movements during the first few reservoir cycles to determine possible requirements for change in reservoir operation. A representative from the Nuclear Cratering Group at this session suggested an approach of deliberatly induced sliding by explosives combined with fluid injection. No minutes were kept of this meeting. The District provided higher authority with a preliminary tendoning plan on 12 March and an on-board review was held on 17 March. This review reduced the District's plan to 65 tendons and increased the number of drain holes to 54.

b. As the slide mass was removed, four MPBX extensometers (L-8, L-9, L-10 and L-11) (plate 6) were installed during April and May 1971, partly for monitoring the slope to determine if movement was occurring which might dictate removal of a larger portion of the rib and provide ongoing safety monitoring during tendoning activities. By late March some rebound of the rock mass manifest in observable opening of joints upstream from the failed wedge had suggested periodic movement rendering safe work on the slope questionable though drilling of drain holes was already underway. Work continued, however, a number of the opening joints were monitored by installation of gage points across the joints. Late in March also, the Engineering Division began efforts to include Stanley Wilson of the firm of Shannon and Wilson as an additional consultant on the problem. A briefing session took place at the site on 12-13 April and Wilson's report was submitted on 15 April.

c. A second meeting with the special consultants, with Geologist Howard Coombs now taking the place of incapacitated Board member Thompson, was held on 19-21 April 1971. At this time the District proposed installation of

31 tendons and 45 drain holes in the slope above the left abutment. This the consultants considered as an interim plan to be started pending further stability studies. They further favored a plan which would have a tendon orientation providing an uphill component of force. Additional geologic studies were recommended over the entire Left Bank Slope, together with studies of potential waves generated from major slides. The consultants concurred in the District proposal for realigning MSH 37, Unit 3B(1) on to an embankment which would assist in buttressing the slope toe. They also concurred in the District proposal to instrument the slope with 8 additional MPBX-type extensometers, 10 inclinometer installations and 12 piezometers. While the consultants agreed that the District's slope stability analysis using a friction angle of 22 degrees and a factor of safety of 1.25 was appropriate, they also requested the District to conduct parallel analysis using a safety factor of 1.15, making a reasonable allowance for uplift. They further recommended against use of water during drilling operations on the Left Abutment Rib until 30 to 50 percent of the ultimate tendon requirements were inplace.

d. On 27 April, the District began efforts to engage the firm of Shannon and Wilson to prepare an instrumentation program and monitoring plan for the Left Bank Slope. The firm was under contract by mid-May and was furnished the District instrumentation plan which had already received consultant approval as a basis for beginning. Efforts were also begun to obtain assistance from Dr. Leopold Muller at the University of Karlsruhe (Germany). Muller had been involved with analysis of the Vaiont (Italy) Slide in 1963. Efforts to retain Dr. Laurits Bjerrum of the Norwegian Geotechnical Institute were also made. Ultimately, Muller was able to work with the District for a time as a special consultant.

e. An analysis of slope stability performed at OCE (Barron) late in April indicated that water in the slope probably had significant influence on its stability. It was suggested that the District consider construction of an extensive drainage tunnel deep behind the slope from which drain holes might be drilled to drain the slope. By early May, drilling for tendon installation in the Left Abutment Rib had begun and by early June about 30 tendons had been installed in the first phase of the work. The Division office concurred in the OCE drainage study recommendation which suggested analysis using a friction angle of 41 degrees assuming rock to rock contact along bedding faults. This was a critical departure from the District's use of a 22 degree friction angle (ϕ) in its analysis. The District disagreed, citing the essentially continuous distribution of clay gouge on major bedding faults, the tested properties (ϕ = 20 degrees) of the gouge and the instrumental character of the DS+122 failure. Furthermore, analysis of older left bank slides also indicated a friction angle of 20 to 22 degrees for a safety factor of 1.0. On the basis of both laboratory and field data the District stoutly defended the use of ϕ = 22.6 degrees, assuming no hydrostatic uplift, in analysis of these rock wedges, indicating that while water conditions on the slope may have influenced the timing of the January failure, the failure was in progress irrespective of water. On the above basis, the District proposed (on 15 May) a total tendoning program of 80 tendons from the DS+122 face and 34 tendons upstream from the DS+122 face at an estimated cost of $1,020,000. The District indicated that it was proceeding with the second phase of tendon installation pending study of the drainage question. As discussion continued between the District and higher authority, the tendoning activity continued.

f. Shannon and Wilson presented a proposed plan of instrumentation on 2 July 1971. The plan called for 20 tandem rod extensometers installed in boreholes inclined 10 to 30 degrees from horizontal. Individual extensometer rods would not be more than 60 feet long and sensors would be grouted in downhole. The plan further called for 8 rock noise sensors and 13 piezometer assembly installations which would combine pneumatic and electric instruments. Leads from extensometers, electric piezometers, and rock noise indicators would terminate in a readout house on the slope 150 feet above road level. In addition, four vertical inclinometers would be installed at critical locations. The District geology staff was not unanimous in accepting the appropriateness of the entire program, especially the design of the extensometers in which transducers were grouted in downhole. However, the proposal was presented to the Board and higher authority for comment.

g. The question of future project damage from large slide-generated waves was of concern to the District during this period. An initial District study in June 1971 concluded that large, high velocity, rock slides from the Left Bank Slope had the potential for generating impulse waves 180 feet above reservoir level immediately across the valley (Souse Gulch) and 90 feet above reservoir level at the dam. Investigations using a three-dimensional hydraulic model were suggested to confirm these studies; the effects of such waves having a seriously damaging effect at the dam and on downstream.

h. A large amount of work was accomplished by the District between February 1971 and the July 1971 Board of Consultants meeting. The District geotechnical staff was mobilized, geologists were borrowed from several other districts to assist in the detailed geologic mapping of the entire Left Bank Slope and to supervise the ongoing subsurface investigation program. The details of the Kootenai Narrows Slide and adjacent areas of the 927 Rib were investigated with 15 core borings and the 914 Rib with three core borings. In addition 5 exploratory borings, 5 deep instrument borings, 45 drain holes, and 33 tendons had been installed and 26 stressed in the Left Abutment Rib. The results of all this activity, together with the proposed instrumental monitoring plan for the slope, were presented to the Board of Consultants, special consultants (Wendell Johnson, Robert Nesbitt, Stanley Wilson and Howard Coombs), and higher authority on 7-9 July 1971. Wilson himself presented the details of the comprehensive instrument plan with an estimated cost of $800,000, including the drilling of instrument holes. In addition, the proposal for locating the section of MSH 37 essentially on an embankment with buttress fills spanning the toe of the 914 and 927/929 Ribs at a cost of $3 million was presented for review, together with alternate but more expensive proposals of constructing a drainage tunnel behind the slope and excavating large portions of the rock ribs. The District's proposal for tendon installation on the Left Abutment Rib included ten 396.5-kip tendons securing the Dirty Shame/E block, oriented N84E -30 degrees from horizontal and eighty-one 396.5-kip tendons installed from the DS+122 face, half to penetrate the DS+80 and half to penetrate the DS, bearing S48E -30 degrees from horizontal. The Board essentially concurred in the District's proposals. In addition, the Board requested drain holes and instrumental monitoring of the DS/C block below the road in the left abutment and, while concurring in the general instrument plan, recommended that the District prepare a plan to monitor the instrumental data, interpret the data, and act on such interpretations. The Board concurred in the District's intent to proceed with hydraulic model studies of landslides to assist in evaluating landslide generated waves and effects as well as the District's intent to drill drain holes at appropriate positions in the 914, 925, and 927 Ribs. The Board further emphasized that the instrumentation system proposed was not intended as an "early warning" system, with respect to an occurrence of a major slide, but that the data, coupled with sound engineering judgment, would provide the basis for future decisions on reservoir operations and the need for additional construction to further improve the stability of the slope.

i. By early September 1971 the tendoning work on the Left Abutment Rib was essentially complete and the hazard alert system was deactivated. Solicitation for the supply and construction of the instrumentation system for the Left Bank Slope was issued on 16 August with an important change to the system; all extensometer installations were to be placed in vertical borings. This major change in design had the effect of changing extensometers into "compressometers", the instruments measuring any downslope displacement in terms of borehole shortening until the instrument is disabled by shear across the borehole. The Board of Consultants was not informed of this change until after the system was installed. A prebid conference was held in September and bids were opened on 28 September; Peter Kiewit Sons' Co. being the low bidder at $1,008,004. The Government estimate was at $815,260.

3.08 Instrumentation of Left Bank Slope.

a. Award of contract DACW67-72-C-0028 to Peter Kiewit Sons' Co. was made on 19 October 1971 and construction of the instrumentation system begun immediately. Subcontractors were Fischback and Moore, electrical; Slope Indicator Co., instruments and final testing; and Soil Sampling Service, instrument installation. Under the terms of the contract, work was to be completed by 15 December 1971. Rollins, Brown & Gunnell, Inc., and Jensen Construction and Drilling Company were contractors for drilling of instrument borings under a separate contract. To minimize environmental damage to the slope, equipment and material access was largely by helicoptor and small tracked vehicles on access trails. Major problems were occasioned by the cold winter weather during December 1971 and January 1972 which slowed both the drilling and instrument installation work considerably, yet the installation work was essentially complete by late January. In addition to normal mechanical problems and drilling fluid freezing, which are common to -10° F temperatures, electric cable jackets shattered as they were removed from the reels. In one instance an extensometer assembly was placed in the wrong borehole; the problem solved by removing the 310-foot-long installation in one piece by helicoptor and placing it in the correct boring. The transmission system to terminal facilities required installation of 350 miles of 19-gauge paired wire and 3-1/2 miles of rigid conduit (20). The final cost of the contract with changes and paid claims was $1,454,298.50.

b. The completed system included the following elements (plate 3):

(1) Four cluster installations underneath the MSH 37 embankment consisting of an extensometer (E) in one boring and a combination of stage piezometers (Geonor Electric) and stationary rock noise sensors in an adjacent boring (PEN).

(2) Four cluster installations, low on the slope, but above MSH 37, consisting of an extensometer in one boring (E), redundant pneumatic and electric stage piezometers in a second adjacent boring (PEP), and a third adjacent boring with an inclinometer casing which included capability for a movable rock noise sensor (NI).

(3) Four cluster installations high on the slope consisting of an extensometer (E) in one boring and redundant pneumatic and electric stage piezometers in a companion boring (PEP).

(4) Five individual extensometer (E) installations including one below and one above MSH 37 in the Left Abutment Rib; the latter being installed by separate contract in 1974.

(5) Two combination pneumatic/electric stage peizometers (PEP) in the Left Abutment Rib.

(6) One pneumatic stage piezometer (PP) low on the 925 Rib.

(7) One combination inclinometer and movable rock noise installation (NI) low on the Left Abutment Rib.

c. The extensometer and piezometer systems were essentially operational by 1 February 1972, 1 year following the slide and less than 3-1/2 months following contract award.

3.09 Construction of MSH 37, Unit 3B(1). The contract for construction of MSH 37, Unit 3B, contract DACW67-71-C-0027, had been awarded to Peter Kiewit Sons' Co., on 9 October 1970 well before the slide. Work on Unit 3B(1), the segment along the Left Bank Slope, was delayed by contract provisions, however, until removal of Libby Dam Builders' aggregate conveyor from the entire length of the slope. This was scheduled for 15 November 1971, and the removal of the concrete batching plant scheduled for 1 January 1972. The alinement and grade of the road segment was changed by contract modification on 29 July 1971, but serious work could not begin until removal of Libby Dam Builders' plant from the area. The contract had a number of field modifications to provide for exploratory and drain hole drilling. This effort, plus some early foundation excavation activities, resulted in considerably more foundation excavation in the troughs of the slope than had originally been anticipated. This work was carried out in close proximity to Libby Dam Builders' effort to stockpile aggregate downstream from the dam; the borrow area at Yarnell Terrace being upstream from the Left Bank Slope. About 20 November 1971, Libby Dam Builders began dismantling the aggregate conveyor and work on the highway segment could begin in earnest. With the instrumentation contract proceeding simultaneously, activity on the slope was complex. By the time the Board of Consultants met late in March 1972, some 3-1/2 million c.y. of gravel and shot rock had been placed and the roadway was essentially to grade. The temporary sluices in the uncompleted dam had been closed and the reservoir had begun to rise. Ultimately the contract for MSH 37, Unit 3B increased in total cost from $6.3 million to $8.7 million with the numerous changes and additions.

3.10 Landslide Analysis and Model Tests.

a. During the winter of 1971-1972, studies were conducted by the District and by the Waterways Experiment Station (WES) on the effects of potential large rock slides into the reservoir from the Left Bank Slope. The purpose of these studies was to obtain realistic values of potential slide velocity and resulting wave runup to better assess possible project and downstream damage. The studies included a review of analysis of other investigators on several historic slides together with model studies. The velocity study was reported in a paper by D. C. Banks at WES. The wave generation study was reported to the Board of Consultants at their meeting on 21-23 March 1972[1/]. Based on these studies and the delineation of potential slide masses, as determined by geologic mapping, slide velocities ranging from 60-80 feet/second were calculated for some masses whereas velocities of 142 to 171 feet/second were calculated for others. Velocities for the Kootenai Narrows Slide were calculated in the range of 76 to 112 feet/second. Velocities determined by physical model tests, though generally lower than the numerical model, varied from 37 feet/second to 192 feet/second. Maximum first arrival wave heights at the upstream face of the dam varied from 8 feet to 43 feet, but generally were in the range of 14 to 23 feet.

b. With this magnitude and variation of velocities and waveheights, a series of various wave height scenerios were presented to the Board and higher authority for consideration at the March 1972 Board of Consultants meeting. The scenerios included failure of the spillway gates with wave heights in excess of 25 feet, rapid drafting of the reservoir to the ogee elevation (2,105 feet) and downstream flooding, the upper section of the dam (above elevation 2,410) subject to shear failure (shear stress 30 percent over allowable) under wave height conditions of 45 feet or more. All large wave runups showed overtopping of the right abutment of the dam, a scenerio which included erosion and destruction of the downstream embankment flanking the buried concrete monoliths. Runups on the right abutment varied from elevations 2,500 to 2,590 feet. All scenerios resulted in extensive powerhouse damage.

1/Much of this data is formalized in WES Research Report H-75-1, Raney and Butler, 1975.

The basic remedial actions presented to the Board and higher authority included construction of a rockfill buttress along the lower reaches of the Left Bank Slope or removal of large masses of rock from the slope, or both. Other schemes considered the construction of concrete shear keys through the potential failure zones on the slope, a scheme possibly to be combined with installation of additional tendons. In addition, schemes to mitigate the wave runup on the right abutment construction of rockfill mounds, breakwaters, and a concrete deflection structure were considered. Estimated costs of the various schemes were as follows:

Buttress fill (remote borrow)	$25 million
Buttress fill and rib removal	$40 million
Shear keys and tendons	$45.5 million
Shear keys alone	$5.2 million
Tendons alone	$85 million
Wave traps (right abutment):	
Breakwaters	$0.5 million
Breakwater and reflecting wall	$3.2 million
Concrete walls	$3.4 million

c. A considerable amount of discussion and lack of unanimity was apparent among the attendees at the March 1972 Board meeting as to the likelihood, magnitude, and effects of additional rock slides into the reservoir. These differences related to mode of failure, the importance of increased fracturing of the rock mass toward the toe of the slope (which extensive exploration confirmed), the velocity of slide movement, and the believability of model studies. In response to several, pertinent questions submitted by the District, the Board:

(1) agreed to raising the reservoir to elevation 2,405 feet (spillway crest) with the option for modification of the plan in event additional slope monitoring and hydraulic model tests indicated a required change;

(2) noted necessity for continued instrumental data evaluation during the initial pool raise and requested that consultant Wilson be kept fully informed of all observational data;

(3) agreed that the District's plan to strengthen the spillway gates to withstand a 25-foot-high wave was prudent but suggested that other measures be considered to insure that such a wave did not result in significant damage;

(4) suggested that the right abutment breakwater or diversion structure be tested in the hydraulic model;

(5) recommended additional drainage in the Left Bank Slope, over and above the District's plan;

(6) recommended that hydraulic model (Caldwell) test procedures include slide velocities in the range of 100 feet/second, that gravel be used in the slide model tests in lieu of crushed rock, and that a hydrograph be determined from the model tests to facilitate estimating of downstream effects;

(7) concluded that sufficient cognizance of seismicity had been taken in the design and construction of the dam; and

(8) reserved comment on the geologic interpretation of the Left Bank Slope pending further examination and review by consulting geologists.

3.11 Construction of Buttress Fill.

a. Prior to the field meeting of geologists from the District, higher authority, and geological consultants in Libby on 26-27 April 1972, the District had already set design work on the buttress fill in motion. While this geological field review was intended to consolidate geologic opinion on the past and potential mode of failure, this purpose was not totally accomplished. The net result was the general agreement that additional rock slides were possible, but when and where they would occur could not be agreed upon. The general feeling was that measures were needed to offset the reservoir buoyancy and drawdown effects. The consultants at this meeting believed the rib segments above MSH 37 not to be a hazard, but advised the continuing design of corrective measures so that the full Board could further consider it when they met in August. They further recommended that the rock ribs above the highway be left inplace and that a remote quarry source provide material for the buttress fill. To compound the diversity of geologic opinion, the District had retained Dr. Leopold Muller of Karlsruhe, Germany, to provide an analysis of conditions at Libby. His preliminary report was presented to the Board of Consultants in August 1972 and finalized in December 1972.

b. The longest meeting of the Libby Board of Consultants took place between 7 and 11 August 1972. A separate geology supplement, in addition to the brochure covering other geological features, stability analyses, and instrumental data, was furnished to all in attendence, providing the most extensive synthesis of such data to date. The data presented included reports on sliding and failure velocities by WES and by Muller (presented by Gerhard Logters representing Muller). Slide model data were also presented (later published by WES). Following a considerable amount of discussion on all the data presented and upon which there was little unaniminity of opinion, the Board of Consultants presented their findings which may be summarized as follows:

(1) The 927 and 909 (left abutment) ribs were the most critical of the four.

(2) Although the likelihood of a major slide might be remote, such a slide could not be tolerated and that emphasis should be placed on prevention of slides by buttressing below the highway, drainage, and/or tendoning above the highway, concurring in the District's proposal to construct a 100-foot-wide buttress;

(3) The velocity of any major slide would probably be in the range of 75 to 125 feet/second.

(4) Concurred in the proposal to have Muller review the WES "velocity report" with emphasis on uncertainties in the rock mechanics aspects which surfaced during meeting discussions.

(5) Data from E-1 at toe of 927 Rib was questioned and replacement of the instrument recommended if reliable data could not be obtained. The importance of a working rock noise system and solution of piezometric data anomalies was emphasized.

(6) There was concurrence with the District's proposal to raise the reservoir to elevation 2,459 feet subsequent to completion of the buttress in the spring of 1973 subject to the results of observed data.

(7) There was no objection to lowering the reservoir to elevation 2,230 feet to facilitate construction of the buttress.

(8) The position was held that no blasting be permitted on the rock ribs because of the possibility of resulting changes in stress conditions.

c. Design of the buttress fill was essentially complete by the end of August 1972. The design provided for construction of two rockfills having nominal widths of 100 feet. The downstream fill was positioned from the dam upstream approximately 1,100 feet along the toe of the 909 (left abutment) and 914 Ribs. The upstream buttress, about 700 feet long, was to be placed at the toe of the 925 and 927 Ribs. The buttresses were designed as dumped rockfill below elevation 2,460 feet (1 foot above normal full pool. Fill material above this point was to be random with an outside rockfill shell. The Dunn Creek Quarry was established 1/2-mile southwest of the dam as a borrow area. Pit run material was used from this source with the bulk of the material ranging from 6 to 36 inches. There were some restrictions on placement of material above and below this range. The Board of Consultants reviewed the buttress design analysis in November 1972 and concluded that the buttress should be strengthened to provide for a safety factor of 1.10 with a 2,460 reservoir and 1 on 1.5 rockfill slopes, estimating that such a fill would also provide a satisfactory factor of safety against an earthquake acceleration of 0.1g, based on stability analyses presented by the District. Further, the Board concurred that tendons above the roadway were not necessary, but recommended a single, deep drain hole through the limiting fault in each rib. The latter were constructed in 1973. The final design of the buttress fill resulted in an average width of 15[illegible] feet.

d. After a prebid conference on 3 October, the contract was awarded to Stewart-Erickson of Seattle, Washington, on 7 November 1972 for $3,840,855. The contract and its modifications ultimately provided for nearly 1.7 million c.y. of rock excavation (quarry) and nearly 1.5 million c.y. of compacted rockfill. The reservoir reached its low level of 2,230 feet about 1 January 1973 and was held there until 1 April. The dumped rockfill was placed at low pool and the compacted rockfill kept pace with the spring rise of the reservoir. Work was essentially complete by 26 August 1973.

3.12 Early Instrument Performance.

a. As with all geotechnical instrumentation programs, the system installed in the Libby Left Bank Slope was not without problems. From late November 1971 through September 1972, an interdisciplinary meeting was generally held weekly in the District office for total coordination during the construction and initial implementation of the system. The meetings always included representatives of the design, geotechnical, and management functions of Engineering Division, Construction Division, and other appropriate staff support as required.

b. The wire extensometers installed in the Left Abutment Rib (Terrametrics MPBX's) immediately after the 31 January 1971 slide were plagued with readout problems which appeared to revolve around the incompatability of the transducers (linear voltage differential transformers (LVDT)) in the instrument head and the direct current (DC) readout system. The original alternating current (AC) readout scheme had been replaced by a DC readout scheme to eliminate apparent changes as a function of cable length. The printed circuit boards, part of the DC system, were plagued with moisture problems and resulting shorting, yielding spurious readings. The amount of electrical wire in the instrument heads also made reading by portable dial gage difficult and with a lack of consistency in readings. By the fall of 1974, the DC system had been removed, the dial gage reading abandoned, the LVTD transducers replaced by linear potentiometers (generally with a 2-inch run), and the AC system reactivated. The MPBX system has subsequently proved excellent and the subsequent MPBX's installed have all utilized this readout method.

c. The piezometer system, consisting of instruments of a pneumatic type from SINCO (Slope Indicator Company) and an electric (vibrating wire) type manufactured by Geonor in Norway, suffered several problems. The two types of pieozmeters did not yield equivalent data and did not always track. The pneumatic piezometers usually read 5 to 15 feet less head than corresponding electrical piezometers. By late June 1972, only 17 of the original 55 electric piezometer sensors were functioning. This problem was solved when, on 8 July 1972, an electrical storm rendered the 17 remaining electric piezometers inoperative and their position beneath the highway embankment made replacement impracticle. Lightning protection had not been included on any of the instrument array to that date.

d. The rock noise system had problems from the beginning. Because the sensors were basically microphones and the system conceived only as a method of counting events, it was not possible to distinguish microseismic noise from radio or other types of noise. Exteraneous noise which could not be easily filtered out plagued the system. The system was further hampered by malfunctioning clock and data logging systems. Beginning in August 1972, the U.S. Bureau of Mines provided technical expertise from their Denver Mining Research Center to assist the District in the evaluation of the problem. This expertise was supplemented by engineers from Pacific Western Engineering Corporation in Bellevue. For 2 months, between August and early October 1972, a team consisting of representatives of the above two organizations, plus geotechnical and electrical representatives from the District and Libby Residency, studied the problem. In October, after exhaustive testing, the team concluded that the system was poorly conceived and designed, cheaply constructed, had little redeeming value, and recommended that it be scrapped and replaced with a system capable of discriminating microseismic noise. It was not yet to be, however, due to contract performance requirements. Early in 1973 the manufacturer was given the opportunity to modify and salvage the system. It was to no avail. By October 1973, the system was permanently shut down, and with the safety of the slope enhanced by construction of the buttress fill, further efforts to monitor microseismic noise as precursers of failure were abandoned.

3.13 Final Board of Consultants Actions.

a. Beginning February 1972, all members of the Board of Consultants, special consultants, and higher authority received a monthly summary on the Left Bank Slope instrumentation program which included both status of the program and an analysis of data. The frequency of this report was reduced to quarterly beginning with September 1973, further reduced after December 1974 and the final summary was submitted to the consultants in May 1975 for review and comment.

b. When the Board of Consultants met in September 1973 they were presented with all of the instrumental data from the slope to that time and recommended no further treatment for the area flanked by the newly completed buttress fill. Even though confronted with some erratic data from the Left Abutment (909) Rib, however, they agreed with the District's proposal for additional instrumentation, but embelished it with four additional short rod extensometers at the cut face across major faults. They saw no reason to consider the roadway below unsafe for public use. They were not able or willing to stipulate specific amounts of instrumental movement which would trigger contingency actions but earmarked movement over prolonged periods and abrupt changes of 0.1 to 0.2 inch or greater for special concern. They further recommended that the District prepare contingency plans and cost estimates for remedial action should such action become necessary. The recommended instrument additions were implemented during the summer of 1974. When the Board and special consultants met for the final time on 9-11 September 1974, they expressed total satisfaction with the instrument program, recommending that extensometer monitoring be continued indefinitely. They did however, suggest that piezometer and inclinometer readings might be drastically reduced and perhaps abandoned after the following drawdown cycle. The Board closed its comments on the Left Bank Slope as follows:

> "Regardless of the stability of the hillside, the rate of downhill creep of this rock slope is of significant engineering interest. The Board knows of no comparable measurements elsewhere, and strongly recommends that the data be published and made available to the profession."

c. The last formal submittal of instrumental data to the Board of Consultants was in May 1975, covering the period January-May after the reservoir had completed its first complete filling and drawdown cycle. The

Board responded in a final letter noting that the minor motions shown by the extensometer array were normal and that the area was stable. They further noted that the piezometer data indicated a free-draining slope and that bouyancy in the slope was believed minor. They noted that changes over time might have some adverse influence on slope stability and recommended continued monitoring on all instrumentation.

3.14 Tendoning of the Cut Face. Between 1 October and 5 December 1975, and continuing into early 1976, data from several instruments at or just behind the highest part of the cut face in the Left Abutment Rib just upstream from the 1971 failure indicated a significant change. Initial motion on extensometer X-4 prompted a field investigation early in December. A series of fresh, "en echelon", North-South tension cracks 20 to 70 feet behind the cut face were observed (plates 6 through 9). These cracks extended from the C-Prime Joint across the face of the DS+122 and disappeared beneath a pocket of shallow overburden on the cres_ of the rib. An additional crack was noted northward above the intersection of the DS+80 and the D Joint. Instrumental data suggested movement of a block bounded by the C-Prime Joint and DS+80 or the somewhat innocuous DS+50. The surface trace of the North-South tension cracks across the face of the DS+122, is upslope from five of the tendon head blocks. While failure of the rock block did not appear imminent, remedial action was clearly indicated. The District considered three potential types of reinforcement from the face; prestressed tendons, groutable rock bolts, and grouted rein- forcing steel. Removal of the block was also considered. Analysis showed that the prestressed tendons would be the least expensive and the most effective and proposed a plan to install 13 face tendons with anchors deep below the DS+80 and DS+50. Following appropriate concurrences the District formulated a contract for the tendon installation which included three additional short rod extensometers and five additional drain holes penetrating the DS+80. The contract was awarded to Central Construction Company on 26 July 1976 for $162,095 and work was completed at a final cost of $305,595. A minor quantity of short rock bolts were installed during installation of face tendons.

3.15 Post-1976 Actions.

a. Instrumental activity on the Left Abutment Rib late in 1981 and at the beginning of 1982 generated several actions of which this report is one. In response to concern for viability of the cable tendons if they should be placed in shear by downslope movement along the DS, DS+50 or DS+80 Bedding Faults, two extensometers (L-17 and L-18) were installed with instrument heads within the tendon field. These were placed to measure motion within the tendon field as the tendons are designed for high strength in tension but not in shear.

b. A warning fence was installed adjacent to the Jersey wall on the cut side of the highway below the Left Abutment Rib cut. The system is designed to be actuated in event of pile of rock debris reaches the highway and to stop vehicular traffic away from a failure area. During 1983, four additional extensometers were added as follows:

o L-19 on the Left Abutment Rib above L-16 was installed to monitor the rock mass above the tendon field.

o L-20 was installed from highway level to monitor the 914 and 915 Bedding Faults and other structutes in the 914 Rib.

o L-21 was installed from highway level to monitor the 927 and Hidden Bedding Faults in the 925 Rib.

o L-22 was installed from highway level to monitor the Hidden and 930 Bedding Faults in the 927 Rib.

The latter three instruments, installed at a flat angle deep into the respective ribs, are intended to replace the vertical (E) extensometers in these areas and monitor the faults at a more favorable geologic angle.

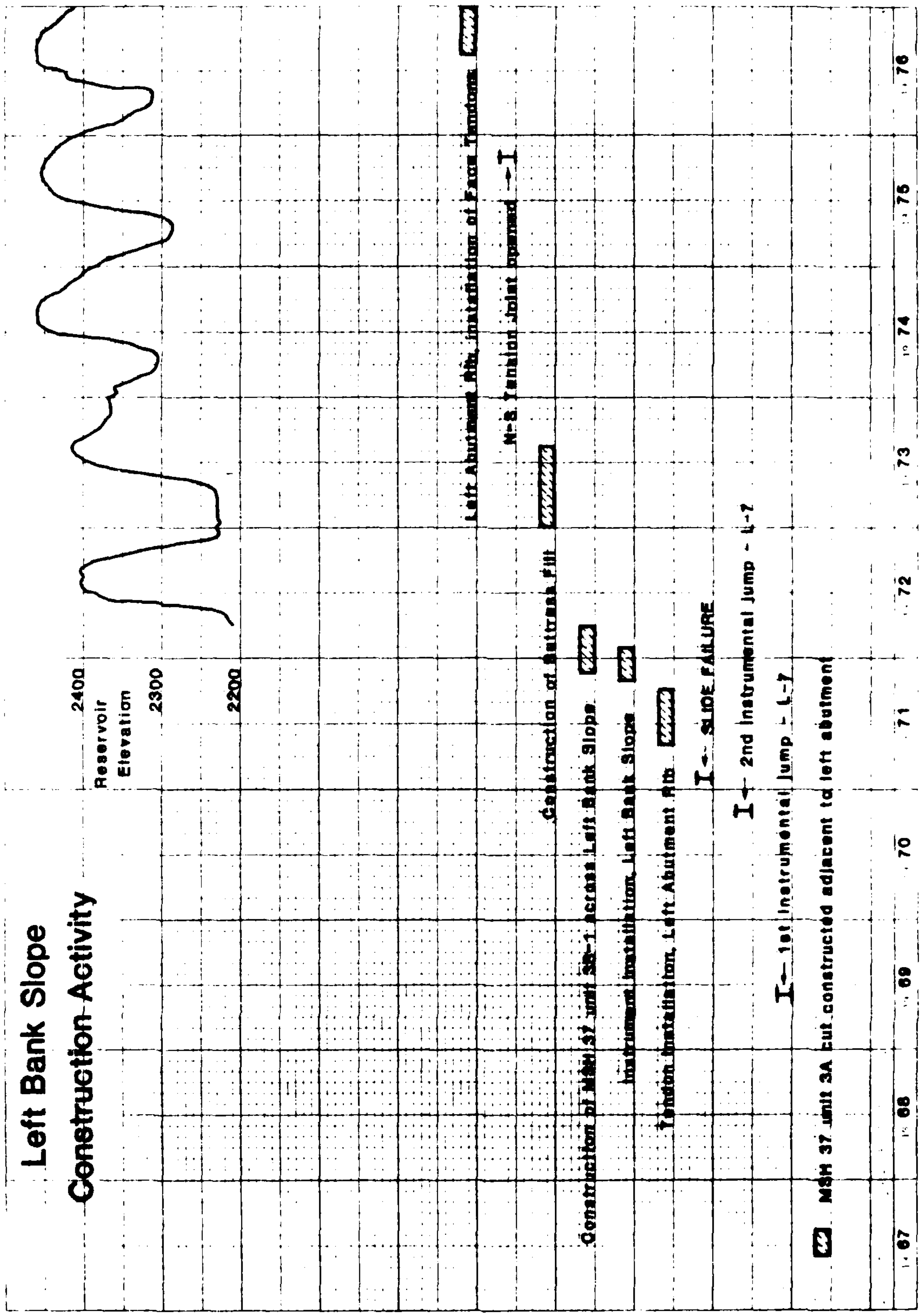
c. In September 1981, the original SINCO readout console was replaed by an Acurex AD 10/10 microprocessor enabling readout from remote stations (District office) and allowing for easier expansion of the readout system. Readings are taken from all extensometer sensors on a weekly basis and data is processed and autoplotted immediately. As necessary, readings are taken at more frequent intervals. Much of the piezometer array is no longer operational. As data has confirmed basic assumptions regarding water in the slope, reading was discontinued in the fall of 1981. Inclinometers continue to be read annually.

SECTION 4. INSTRUMENTAL ANALYSIS

4.01 General. Instrumental analysis of each of the five defined rock ribs will be discussed separately in succeeding paragraphs. The ribs include the Left Abutment (909) Rib, 914 Rib, 923 Rib, 925 Rib, and 927 Rib. Wedges which geologic analysis indicate have the greatest potential for failure are considered separately. Key extensometer plots for appropriate fault zones and major joints are included as figures in this section to assist the reader in following the text. Geologic diagrams of extensometers and a discussion of extensometer instruments are presented in appendix A. Complete plots of all extensometers may be found in appendixes B and C. Plots of piezometers are shown in appendix D. A number of instruments exhibit annual cyclic changes which are attributed to expansion and contraction of the rock mass in response to variations in the mean ambient temperature. Analysis looks beyond these cyclic changes considering them as "noise" in the overall condition of the slope. A chart of construction activity and associated pool levels is shown on figure 4.1.

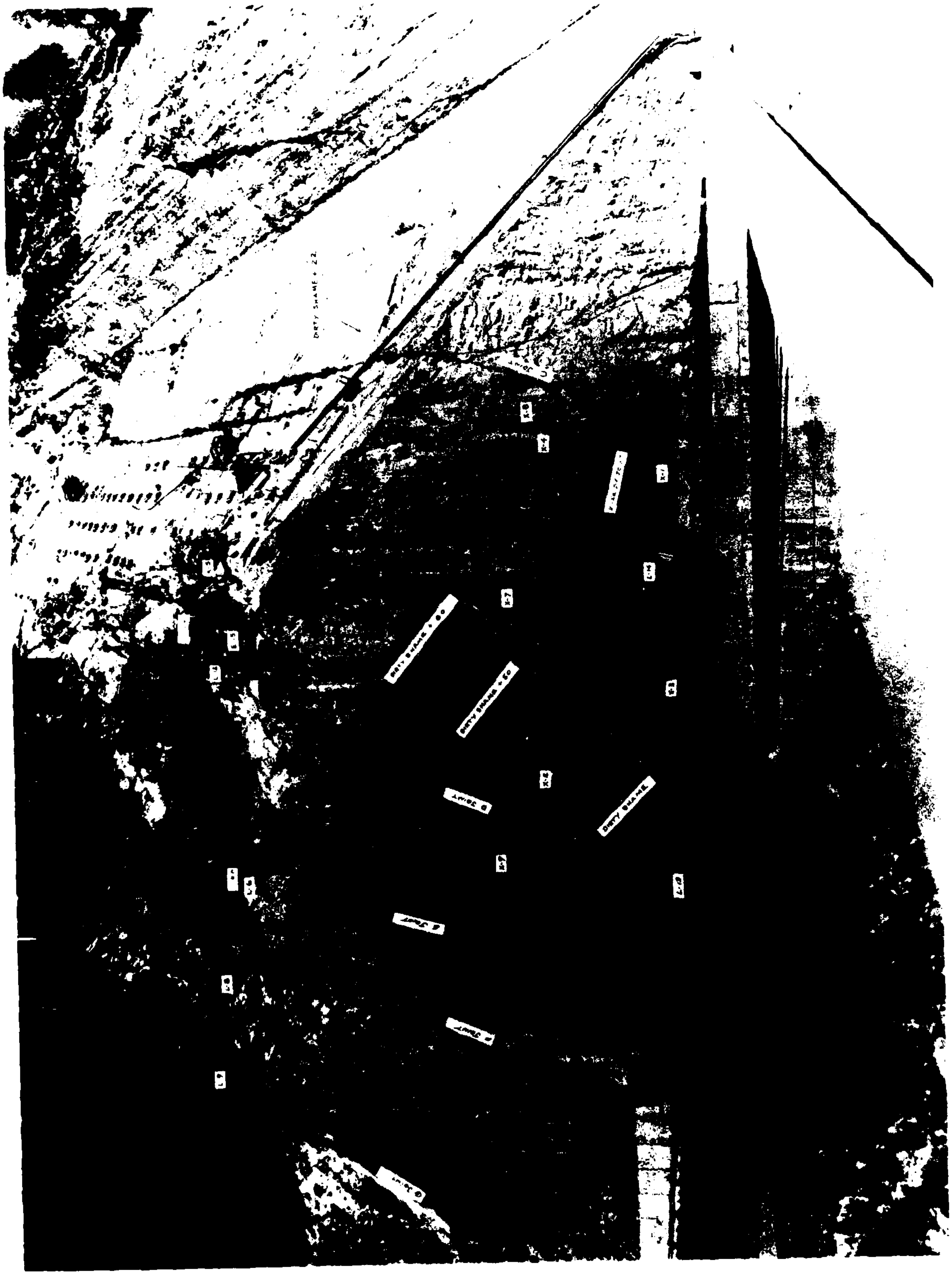
4.02 Left Abutment Rib.

a. Geology. The Left Abutment Rib (plate 3), sometimes referred to as the "909 Rib" or "Dirty Shame Rib," is the rock mass which forms both the left abutment of the dam and the rib above the MSH 37 highway cut adjacent to the dam. It consists of several significant blocks bounded by the following geologic structures: the A, C, D, E, and F east-west trending joints and the DS+122, DS+80, DS-50, DS, and 909 Bedding Faults (figure 4.2, plate 3, plate 6). Of these, part of the DS+122/A Block failed in January 1971 and the entire wedge was removed. Blocks bounded on the downstream side by the C-C Prime Joint set and on the upstream by the successively lower DS+80, DS+50, and DS Bedding Faults have been tendoned. Of these, only the DS/C-C Prime block does not daylight in the MSH 37 cut, however, the highway cut has left only a 60-foot-wide septum of support at ditch level. The block does daylight about elevation 2,300 feet just upstream from the dam behind the feathering edge of the buttress fill (plate 4). In addition, smaller "piggyback" blocks, DS/F, DS/E, and DS/D daylight in the cut. The rock mass bounded by the C and D Joints and the DS and DS+122 is reinforced by the main tendon field and the face tendon field; though, in the case of the face tendons, the anchors are in the DS fault zone. A portion of the DS/E block is reinforced by the six upstream tendons, but this has no effect on the near face blocks. Thus, together with upper face blocks, upstream from the D Joint, the mass bounded by the DS, E, and D Joints are not directly affected by reinforcement. While most of the bedding faults and east-west joints are relatively consistent and their locations predictable, the DS+50 and the D Joint vary from this pattern. The surface trace of the DS+50 abruptly stops about 15 feet above the cut toe with the plane of weakness transferred to a "river dip" joint also exposed in the face (figure 4.2). The D Joint can be traced no further upslope than the 2,730 contour where it ends against a north-south joint. The plane of weakness appears to be transferred to the D splay joint at elevation 2,630 feet. The D splay joint trace can be seen on the surface of the DS+122 face, continuing



Left Bank Slope
Construction Activity
2400
Reservoir
Elevation
2300
2200
Left Abutment Rib, installation of Face Tendons
N-S Tension Joint opened
Construction of Buttress Fill
Construction of MSH 37 unit 3B-1 across Left Bank Slope
Instrument Installation, Left Bank Slope
Tendon Installation, Left Abutment Rib
SLIDE FAILURE
2nd Instrumental jump - L-7
1st Instrumental jump - L-7
MSH 37 unit 3A cut constructed adjacent to left abutment
67
68
69
70
71
72
73
74
75
76

Figure 4.1



Left Abutment Rib & MSH Cut Face

FIGURE 4.2

to the C Prime Joint. A North-South Tension Joint is exposed as a series of en echelon cracks across the face of the DS+122 from the C Prime Joint (plate 6). While such joints generally exhibit a lack of continuity, this one appears to extend to some depth below the DS. The feature appears to strike about N10E and dip 58-60 degrees east into the slope. There is no evidence to suggest that this joint extends upstream of the D Joint or downstream of the C Prime Joint. An upper north-south to northeast trending joint zone is present high on the upper slope generally between elevations 2,700 and 2,750 feet. The zone is a complex of joints striking N10E to N50E generally dipping east into the slope about 60 degrees. A gentle river dip joint in this zone forms a narrow ledge across the exposed face of the DS+122 between L-11 and north of L-16 to the crest of the rib. The zone marks the downslope limit of the "pluckout" between A and C joints.

b. Instrumentation. The Left Abutment Rib is presently monitored by 11 Terrametrics-type extensometers (MPBX's) encompassing several generations of instrument development, 9 single point rod extensometers (X rods), 3 sets of multiple piezometers, and 2 vertical SINCO-type tandum rod extensometers (tables 4-1 and 4-2). Two MPBX's have been abandoned due to operational difficulties and one (L-7) was destroyed during the 1971 slide. In most cases, downslope movement is recorded by borehole extension of the MPBX's, designated with an L, and the short rods, designated with an X. The position of the instrument head of L-11 and X-2 cause these instruments to be exceptions, however. Downslope movement on the vertical extensometers, designated with an E, is recorded by compression.

c. Extensometer Analysis.

(1) Dirty Shame (Figures 4.3, 4.4, Plate 7). Monitoring for movement on the DS Bedding Fault has been continuous since June 1967. L-6 indicates a clear record (figure 3.2 and appendix B) of the 0.13-inch expansion (borehole extension) of the rock mass during excavation of the original highway cut in 1967. Of this expansion, 0.07 inch took place on the DS (see appendix B); L-6 also faithfully recorded about 0.03 inch compression during installation of the upstream tendon field in mid-1971. Subsequent movement has been monitored by six sensors on the upper slope and five sensors on the cut face and lower slope (figures 4.3, 4.4). Other than the somewhat wild gyrations of L-11 in the early 1970's and the apparent compression on L-6 in 1973 which did not continue after transducer replacement in 1973, little adjustment on the DS had occurred beneath the upper slope prior to 1980. Beginning in 1980, however, borehole extension across the DS in L-12A, L-11, and L-16 is clearly indicated over and above the cyclic background. The motion low on the upper slope (L-12A) had abated by mid-1981, but movement high on the upper slope (L-11 and L-16) continued, and by the end of 1982, extension in both boreholes was on the order of 0.25 inch. However, L-11's crossing of the DS is downstream from the A Joint. Movement on L-11 stabilized during 1983. The movement on L-16 ceased during the first half of 1983 but the instrument began to register additional borehole extension in September 1983 which by the end of the year aggregated a total of 0.40 inch. The magnitude of seasonal cyclic change on L-6A and L-8 increased during 1982 and 1983. About 0.025 inch extension was

TABLE 4-1

LEFT ABUTMENT RIB - EXTENSOMETER LISTING

Instrument	Service Date	Head Elev	Lambert Bearing	Angle fr. Horiz (Degrees)	Total Depth	Location N	Location E	No. Anchors	Principal Structures Monitored	Status
L-6	(May 67-Apr 79)	2,607.6	S60 E	+1	204.0	567,296	590,637	4	DS+80, Brknzn, DS	abandoned
L-6A	(Sep 79)	2,611.5	S59.5 E	-1	165.0	567,292	590,640	6	DS+50, DS	operational
E-6	(Mar 72)	2,416.1	—	vert.	302.7	567,394	590,351	9	DS, 909	operational
L-7	(May 67-Jan 71)	2,585.2	S71 E	+5	204.0	567,135	590,510 5/	4	DS+122	destroyed 1/
L-8	(Apr 71)	2,619.2	S60 E	-5	114.0	567,328	590,679	4	DS, E	operational
L-9	(Apr 71)	2,630.1	S12 E	-5	198.3	567,344	590,720	4	F, E, D, D Splay	operational
L-10	(May 71)	2,569.6	S66.75 E	-5	218	567,188	590,570	4	C, DS80, DS	operational
L-11	(May 71)	2,740.3	S76 E	-5	200.3	567,044	590,853	4	C, DS80, DS50/AJ+/DS	operational
L-12	(Sep 71-Sep 79)	2,608.0	S73 E	-4	183.4	567,239	590,624 5/	4	DS80, DS50, DS	abandoned
L-12A	(Sep 79)	2,636.0	S75.5 E	-2	184.0	567,221	590,667	6	DS80, DS50, DS	operational
L-13	(Nov 72)	2,485.8	S70 E	-10	350.3	567,310	590,584	6	NS JT 909 and below	operational
L-14	(Jun 74)	2,490.8	S62 E	-2	98.3	567,250	590,552	6	DS	operational
L-15	(Jun 74)	2,604.7	vert.	90	121.5	567,241	590,606	6	DS80, DS50, DS	operational
L-16	(Jun 74)	2,759.5	S83 E	-2	161.3	567,100	590,863	5 2/	DS80, DS50, DS	operational
L-17	(Aug 82)	2,635.0	N 84 E	-13	137.0	567,163	590,667	6	DS80, DS50, DS	operational
L-18	(Aug 82)	2,595.0	N 84 E	-13	132.9	567,192	590,606	6	DS80, DS50, DS	operational
L-19	(Nov 83)	2,829.3	S 81 E	-5	162.3	567,072	590,963	6	DS+80, DS+50, DS	operational
X-1	(Jul 74)	2,486.9	S48 E	+5	40 ±	567,230	590,541	1	UJt	operational
X-2	(Jul 74)	2,517.9	S85 E	+20	40 ±	567,291	590,583	1	DJt	operational
X-3	(Jul 74)	2,490.0	S62 E	+5	40 ±	567,280	590,570	1	DS	operational
X-4	(Jul 74)	2,514.7	S62 E	+5	40 ±	567,221	590,541	1	DS+80	operational
X-5	(May 76)	2,615 ± 3/	N 42 W	-51	60.9	567,222	590,622 5/	1	NS crack	operational
X-6	(May 76)	2,610 ± 3/	N 45 W	-25	61.0	567,199	590,621 5/	1	NS crack	operational 4/
X-7	(Nov 76)	2,525.5	S72 E	0	30.0	567,252	590,561	1	DS+50	operational
X-8	(Dec 76)	2,518.2	S52 E	0	40.5	567,215	590,536	1	UJt	operational
X-9	(Dec 76)	2,530.8	S72 E	0	40.5	567,308	590,600	1	DS	operational

1/Destroyed during slide of 31 January 1971.
2/Deep anchor wire lost during installation.
3/Map elevations, no formal survey.
4/Vernier only.
5/Coordinates scaled from topo map.

TABLE 4-2

LEFT ABUTMENT RIB - SUMMARY OF PIEZOMETER OBSERVATION

Location	Piezometer No.	Sensor Elevation	Remarks
Near DS and DS+80	PEP 12-4	2,592	Above pool, occasional peaks up to 45 feet in Jan 1974; none since 1978.
	PEP 13-3	2,588	Above pool - has shown no head.
	PEP 13-2	2,513	Above pool - fairly consistantly indicates 10-20 feet of head since 1973.
	PEP 13-1	2,476	Above pool - generally shows no head since apparent peak in 1975.
Near 909 Fault	PEP 12-3	2,435	Above pool - peaked 10-15 feet in 1976 none since late 1979.
	PEP 12-2	2,451	Indicated 10-15 feet of head until mid-1973. None since late 1979.
	PEP 12-1	2,414	Generally indicates 20 to 30 feet of head when pool is below piezometer.
	PEP 22-6	2,413	Indicated ± 20 feet residual head during low pools prior to 1981.
	PP 22-5	2,375	Generally follows slightly below pool.
	PP 22-4	2,339	Generally follows slightly below pool.
	PP 22-3	2,322	Generally follows slightly below pool.
	PP 22-2	2,278	Generally follows slightly below pool.
	PP 22-1	2,227	Generally follows slightly below pool.

observed on X-3 near the toe of the highway cut beginning in mid-October 1983 and apparently leveling off by the end of January 1984 coincidental with a similar amount on X-1 across the C-Joint. The instrumentation suggests downslope creep of the rock mass above the DS upslope from the tendon field. The recent installation of L-19 is designed to confirm or deny this. A minor amount of long-term adjustment may be occurring beneath the lower slope. This was registered by E-15-1 early in 1980, by E-6-6 in the mid-1970's, and by a long-term creep on L-14 and X-9.

(2) Dirty Shame+50 (Figure 4.5, Plate 8). Adjustments across the DS+50 tend to be confusing, but total recorded movements are small. High on the slope, the anomalous compression across this fault, registered on L-16 during the late 1970's, appeared more indicative of stress from below the fault plane than from above. Late in 1979 and early in 1980, nearly 0.1-inch extension was indicated which has subsequently fluctuated seasonally, the most recent extension late in 1982. This movement arrested early in 1983. Contrariwise, L-11 and L-12A suggested that essentially the opposite was happening. Low on the slope, E-15 suggests a stepped downslope movement aggregating 0.1 inch in the last 8 years; however, X-7 on the face confirms less than 0.02-inch compression since the beginning of 1979. Overall, these adjustments do not appear to be indicative of significant movements.

(3) Dirty Shame+80 (Figure 4.6, Plate 9). Three instruments (L-11, L-12A, and X-4) show a remarkably consistent cyclic change across the DS+80 with a midwinter extension peak and a midsummer compression trough. There is a consistent long-term trend into extension, however. The movement was first detected at the face (X-4) in mid-1975 and high on the slope by mid-1979 on L-11. The magnitude of the annual cyclic "noise" fluctuation is on the order of 0.05 inch. Overall, total motions on the order of of 0.38 inch at the cut face and 0.18 inch higher on the slope are indicated. Since late 1979, the three sensors have shown on the order of 0.1-inch extension. However, only a slight bit (0.04 inch) of long-term extensional creep has been registered by L-16 across the DS+80 which is inconsistent with the data from L-11. Low on the slope E-15-4 registers no significant change. Downstream from the C Joint 0.04 inch extension occurred across the DS+80 late in December 1983 but had stabilized by January 1984 (L-10, appendix B). This apparent DS+80 movement may be related to C-C Prime system however.

(4) C-C Prime Joint (Figure 4.7). Sensors monitoring the C-C Prime system above the DS+80 all are indicative of downslope movement of the block upstream as early as 1972 (L-11). Beginning in 1979 and with addition of X-8, there has been a continuing trend in this direction, though total movement low on the slope is less than 0.1 inch. The apparent anomalous compression of L-11 is due to the head of the instrument being downstream of the C Prime Joint in the downstream "stable" block; whereas, most instrument heads are in the "mobile" block. Thus, the compression recorded, 0.1 inch in 1974 and an additional 0.1 inch between 1978 and 1980 would indicate downslope movement of the upstream block along the C-C Prime system. The 0.03-inch extension late in 1982 was largely negated by further compression in 1983. Total borehole shortening across the C-C Prime registered by L-11 since 1971 is 0.2 inch.

Late in December 1983, X-1 registered extension across the C Joint at the toe of the slope on the order of 0.025 inch (This was followed on X-8 in January 1984 by extension of the same magnitude). Thus, all the sensors crossing the C-C Prime system indicate minor downslope movement of the block upstream from this structure. While the record of L-10 shows the late December 1983 movement to be on the DS+80, it is probably the unique position of the instrument collaring between the C and C Prime segments which appears to cloud the interpretation.

(5) D Joint (Figure 4.8, Plates 7, 8, and 9). Early data prior to the transducer change late in 1973 suggest some adjustment across the D and D Splay system (extension on the D and compression on the D-Splay) (Refer to L-9, appendix B). Subsequently, adjustments have continued to occur notably during the 1978-1980 period and again in 1982 (L-9 (2-3)). The face extensometer (X-2) showed an annual cyclic variation on the order of 0.03 inch for several years (see vernier plot) and has shown continuing but decelerating borehole compression which by the end of 1983 approaches nearly 0.25 inch. This suggests that the rock wedge upstream from the D Joint is in downslope motion since late 1979 or early 1980. The data suggests continued, periodic adjustment along the D Joint and perhaps loosening of a highly jointed face block (figure 4.2).

(6) E Joint Zone (Figure 4.9, Plate 7). Data across this zone suggests an upstream motion across this zone beginning late in 1973 and continuing in a series of steps. A total of 0.3 inch is indicated; the most recent step occurring throughout 1979 but no movement since. The lack of motion on L-8 indicates no downslope component. Some, if not all, of the upstream extension appears to be taken up by compression across the F zone (see appendix B, L-9).

(7) North-South Tension Joint (Figure 4.10, Plate 6). The North-South Tension Joint which is exposed as a series of en echelon cracks across the face of the DS+122 upstream from the C Prime Joint and downstream from the D Joint is monitored by X-5 and X-6 at shallow depths. Both instruments have reflected cyclic thermal expansion and contraction of the joint since instrument installation late in 1976, with borehole extension peaking in late winter (joint expansion, rock mass contraction) and borehole compression peaking in the fall (joint compression, rock mass expansion). Of greater concern, however, is the extension indicated across what is interpreted to be the same north-south joint in L-13 at the toe of the cut below the DS. Extension began on this zone about 120 feet behind the toe of the face late in 1981 and continued in step form through 1982. The extension was quiesent during the first half of 1983, beginning again in July. Total extension observed about 0.[illegible] inch since late 1981. This tension joint exhibited signs of opening late in 1975, which prompted installation of the face tendons the following year. The deeper strain is suggestive of movement of block bounded by the C Joint, North-South Tension Joint, and an undefined bedding fault below the DS but above the 909. The lower portion of such a block would be buttressed by the rock mass between the dam abutment and the toe of the cut, but a large toppling failure would be possible.

(8) 909 Bedding Fault (Figure 4.11, Plate 3). No real movement can be confirmed across this fault. The long stable (since 1975) condition shown by L-13 (1-6) across this zone above and beyond instrumental fluctuation, together with a similar situation for E-6-3, suggests stability. The sharp 0.04-inch extension on E-6-3 at the end of 1981 is suggestive of an upward movement of the block above the 909.

d. Piezometer Analysis. A summary of piezometer observations is presented in table 4-2. Plots of piezometer data are shown in appendix D. In general, piezometers located below elevation 2,459 feet respond to pool fluctuations with little or no time lag. A few piezometers have exhibited residual head when the pool drops below the piezometer elevation. The most significant of these are as follows:

Location	Piezometer No.	Remarks
909 Fault	PP-22-6	Residual head at low pool increased to about 70 feet in 1976, diminishing to 0 in 1981.
	PEP 12-1	Residual varies from 20 to 35 feet.
DS & DS+80	PEP 13-2 (2513)	10 to 20 feet of head consistently.

With these exceptions, piezometer data generally indicates that the rock is relatively free draining for the pool-drawdown rates experienced. The exceptions noted are not believed to be very significant considering the magnitude of residual head and the presence of the buttress fill. Similarly, in those few instances where peaks of head have occasionally occurred high on the slope, the measured head is not generally large and is therefore not of great concern.

e. Inclinometer Analysis. Readings from NI-5 in April and June 1983 imply several very small offsets downslope. This possible movement, totalling about 0.15 inch is below the 909 fault. This is not entirely confirmed by the other set of grooves, nor is it totally dependable, being near the limit of accuracy of this type of instrument. A close examination of previous records suggests that these small movements have accumulated with time at three locations. Two of these locations each indicate a gradually developing offset of less than 0.04 inch, while at the third location an apparent offset of 0.08 inches has developed somewhat erratically. It is questionable whether any or all of this represents real movement or is a problem with the casing such as that experienced in NI-2 in the 925 Rib.

f. Conclusion.

(1) While minor adjustments have continued to occur along the C-C Prime system, the Dirty Shame Bedding Fault and D Joint, the principal indication of possible future failure is high on the slope and is associated with the DS Bedding Fault. If failure should occur, it would likely happen

along a probable, (but unmapped) river dip or ramp type joint which forms a ledge across the DS+122 slope just below L-16. Only a small upstream part of the rock mass above this feature is influenced by the tendon field.

(2) There are also indications that adjustments are occurring on the C-C Prime/DS+80 block which could, in time, portend failure.

(3) The series of step strains deep on the North-South Tension Joint and minor extension on the Dirty Shame and C Joint at the cut face indicate some continued roadward expansion of the rock mass near the cut face.

(4) Some loosening and movement of what is interpreted to be facial blocks upstream from the D Joint appears to be continuing.

4.03 914 Rib.

a. Geology. The 914 Rib is bounded by the L Joint and the 914 Bedding Fault (plate 3). A larger wedge is defined by the L Joint and the 915 Bedding Fault. The troughs formed by these structures plunge 30 degrees valleyward. Subsurface investigation reveals the 914 Rib to be closely jointed and faulted from the toe to the top, with a high percentage of open structures. Recurrent and recent movement along some joint faces are evidenced by smeared dendrites and by slickensides on unstained joints. The rib is divided into upper and lower segments by a north-northeast trending fault which appears to have offset the 915 and 914 Bedding Faults in a left-lateral fashion.

b. Instrumentation. The 914 Rib is monitored by three SINCO-type vertical tandum rod extensometers (E4, E17, and E18), four sets of multiple piezometers, and one inclinometer. The status of these instruments is shown on tables 4-3 and 4-4. A Terrametrics-type, 8-anchor, MPBX (L-20) was installed in this rib at highway level in October 1983.

c. Extensometer Analysis. In 1973 and 1974 there was a slight suggestion of rock mass bulking on the 914 and 915 Bedding Fault system, but the order of motion is nearly at the instrumental limit (0.02 inch). The somewhat anomalous 0.2-inch compression on the totalizer sensor of E-4 (see E-4-0, appendix C) is not accounted for by the sum of other sensors. However, downslope movement of surficial segments of the rib, well outside the 914 Bedding Fault, is suggested during the 1973 and 1974 pool rises. Less than 0.1 inch can be accounted for, movement that appears to have ceased after the 1974 pool rise. The sensor closest to the surface, E-4-7, failed in mid-1975.

d. Piezometer Analysis. Plots of piezometer data are shown in appendix D. A summary of piezometer observations is shown on table 4-4. In general, piezometers located below elevation 2,459 feet respond to pool fluctuations with little or no time lag. This indicates that the rock is relatively free draining for the drawdown rates experienced. Where peaks in head have occurred above pool level, except for PP-21-7, the measured head is not generally large and is, therefore, not of concern. The sharp peaks shown by the plot of PP-21-7 in 1974 and 1975 may reflect either seasonal pool pressures or instrumental problems in that the piezometer stopped working in mid-1975 following an apparent high peak.

TABLE 4-3

914 RIB AND 923 RIB - EXTENSOMETER LISTING

914 Rib	Service Date	Head Elevation	Total Depth	Location N	Location E	Principle Structures Monitored	Status
E-4	Dec 1971	2,343.0	321.3	567,974	590,755	914, 915	Operational except sensor 7 not operational since June 1975
E-17	Feb 1972	2,674.4	376.4	567,745	591,207	914, 915	Operational
E-18	Feb 1972	3,216.9	300.6	567,517	592,115	914, 915	Operational
L-20	Nov 1983	2,517.7	486.5*	567,886	591,006	914,915	Operational
923 Rib							
E-3	Dec 1971	2,399.6	284.0	568,324	591,229	917, 920, 923	Operational
E-14	Dec 1971	2,742.6	310.4	568,249	591,718	917, 920, 923	Operational
E-16	Jan 1972	3,250.6	540.0	568,143	592,416	917, 920, 923, 927	Operational except sensor 4 not operational since June 1977

*Hole bears S70E down 5 degrees.

TABLE 4-4

914 RIB - SUMMARY OF PIEZOMETER OBSERVATIONS

Location	Piezometer No.	Sensor Elevation	Remarks
Above 914 Fault	PEP 4-4	2,550	Above pool - occasional 10-15-foot peaks.
	PP 21-6	2,380	Several ± 20-foot peaks 1972 and 1973, lost in 1973 after apparent ± 350-foot peak.
	PP 21-5	2,306	Followed slightly below pool until becoming inoperative late 1973.
	PP 21-7	2,251	Generally followed pool, but wth several sharp 100-foot + peaks in 1974 and 1975, became inoperative in 1975.
Near 914 Fault	PEP 9-4	3,114	Above pool - no head.
	PEP 4-3	2,510	Above pool - no head.
	PP 21-4A	2,287	Generally followed pool until becoming inoperative in late 1973.
	PP 21-3A	2,237	Generally follows pool.
	PEN 4-4	2,233	Became inoperative in 1972.
	PEN 4-3	2,202	Became inoperative in 1972.
Between 914 & 915	PEN 4-2	2,166	Lost in 1972.
	PP 21-2	2,151	Erratically followed pool until lost in 1973.
	PP 21-1	2,015	Generally follows pool but is erratic, may be calibration problem.
Above 915 Fault	PEP 9-3	3,022	Above pool - no significant head.
	PEP 9-2	2,980	Above pool - no significant head.
	PEP 4-2 & 2A	2,419	Generally responds behind and below pool.
	PEN 4-1	2,126	Lost in 1972.
Near 915 Fault	PEP 9-1	2,931	Above pool - generally has 10- to 30-foot head.
	PEP 4-1 & 1A	2,350	Generally follows slightly behind and below pool.

e. Inclinometer Analysis. No movement was detectable up to 1977. The instrument can no longer be read (since 1977) due to movement of surficial rock block.

f. Conclusions. No instability of the 914 Rib is indicated by the vertical extensometers.

4.04 923 Rib.

a. Geology. The 923 Rib (plate 3) consists of a upper or "hanging" block high on the slope, defined partly by either the 917, 920, or 923 Bedding Faults. The downstream extent of the "hanging" block has not been identified by a known east-west joint due to the paucity of bedrock outcrops and the lack of exploration, but such a boundary undoubtedly is present beneath the colluvium. The "hanging" block is transected by the Q Joint which effectively divides it into a smaller, lower mass and a larger, upper mass. Low on the slope the innocuous area of bedrock exposure around E-14 (plate 3) is considered part of the 923 Rib through it may be the residual portion of a block which failed prior to the last glaciation.

b. Instrumentation. The "hanging" block portion of the 923 Rib is instrumented by one SINCO vertical tandum extensometer (E-16) and one multi-stage piezometer. The lower slope is instrumented by two vertical extensometers (E-3, E-14), two multiple piezometers, and one inclinometer. Both of these extensometers monitor the 917, 920, and 923 Bedding Faults. Status of the instruments is shown on tables 4-3 and 4-5.

c. Extensometer Analysis. The only motion shown high on the slope on the 917 Bedding Fault (figure 4.13) is an even seasonal cyclic movement of the surficial block. This is attributed to changes in the seasonal ambient temperature of the surficial rock mass. A somewhat cyclic bulking of the toe of the rib across the 920 Bedding Fault is also apparent from the E-3-3 data (figure 4.14) and a long-term bulking of the toe across the 923 Bedding Fault (figure 4.15) began late in 1975, with total motion on the order of 0.05 inch during the subsequent 7-year period. No other movement is indicated.

d. Piezometer Analysis. Plots of piezometer data are shown in appendix D. A summary of piezometer readings is presented in table 4-5. Piezometers PEN-3-1 and PEN-3-3 are the only piezometers below pool level in this rib that have been read for any length of time. The record shows that the piezometer level of PEN-3-1 apparently lagged well below the pool until the piezometer failed in 1975. Ths consistent lag nearly parallel to the pool suggests that the piezometer elevation or calibration may have been in error. A similar situation existed with piezometer PEN-3-3, except that the readings through 1974 indicate apparent piezometric levels consistently above the pool. Piezometer PEP-3-1, located well above pool level, has shown numerous peaks up to about 50 feet of head, apparently reflecting the effects of seasonal rainfall and snowmelt.

TABLE 4-5

923 RIB - SUMMARY OF PIEZOMETER OBSERVATIONS

Location	Piezometer No.	Sensor Elevation	Remarks
Near 917 Fault	PEP 7-4	3,195	Above pool - no head.
	PEP 3-4	2,674	Above pool - no significant head.
	PEN 3-4	2,329	Became inoperative in 1972.
Near 920 Fault	PEP 7-3	3,107	Above pool - no significant head.
	PEP 3-3	2,585	Above pool - no significant head.
	PEP 3-2 & 2A	2,543	Above pool - no significant head.
	PEN 3-3	2,239	Consistently ± 80 feet above pool until lost in 1974 (may be elevation error).
Near 923 Fault	PEP 7-2	3,015	Above pool - occasional 20- to 30-foot peaks 1972-1974, steady since then.
	PEP 7-1	2,981	Above pool - no head.
	PEP 3-1 & 1A	2,493	Above pool - numerous irregular peaks, to above 50-foot head.
	PEN 3-2	2,189	Lost in 1972.
	PEN 3-1	2,149	Followed about 100 feet below pool, lost in 1975.

e. Inclinometer Analysis. There has been no detectable movement on NI-3.

f. Conclusions. There is a slight suggestion of bulking of the rock mass in the toe area. No indication of downslope movement on major bedding faults is found.

4.05 925 Rib.

a. Geology. The 925 Rib is bounded by the 927 Bedding Fault on the upstream side and the R Joint on the downstream side. Many smaller and less significant joints have been mapped on the rib. A high percentage of joints have been identified in the subsurface towards the toe of the rib and again at midslope in the vicinity of E-13 (plate 3).

b. Instrumentation. The 925 Rib is monitored by three SINCO-type vertical extensometers (E-2, E-12, E-13), four multistage piezometer installations, and one inclinometer. All three extensometers monitor the 927 Bedding Fault, and the lower two also monitor the 928 Bedding Fault. Status of the instruments is shown on tables 4-6 and 4-7. A Terrametrics-type 8-anchor MPBX (L-21) was installed at highway level in October 1983.

c. Extensometer Analysis. No discernible motions along major bedding faults are indicated. During construction activity in 1972 and continuing until early 1975, about 0.25 to 0.30 of compression, presumably across a shallow bedding fault near the toe, was registered by E-2 (appendix C). This suggests either downslope movement of the block above this surficial bedding fault or simply compression of the surficial mass by the weight of the highway fill. In either event, no movement has taken place since early 1975. A seasonal cyclic movement is seen on the near-surface sensor of E-12, probably due to expansion and contraction of the surficial rock mass due to seasonal ambient temperature change.

d. Piezometer Analysis. Plots of piezometer data are shown in appendix D. A summary of piezometer observations is shown on table 4-7. In general, piezometers located below elevation 2,459 feet respond to pool fluctuation with little or no time lag. This indicates that the rock is relatively free draining for the drawdown rates experienced. An exception to this is piezometer PEP-20-5 which has shown an erratic residual head during some low pools. Several piezometers high on the slope registered seasonal peaks during early years, probably reflecting snowmelt and/or rainfall. The fact that these peaks did not persist later probably attests to the effectiveness of drain holes drilled into the slope (plate 10).

e. Inclinometer Analysis. No detectable movement to date on NI-2. (TV camera inspection in July 1972 shows rotational slippage of a joint in inclinometer casing just above Hidden Fault, causing disturbed readings below that level.)

f. Conclusions. No indication of downslope movement of this rib along major bedding faults is found.

TABLE 4-6

925 RIB AND 927 RIB - EXTENSOMETER LISTING

925 Rib	Service Date	Head Elevation	Total Depth	Location N	Location E	Principle Structures Monitored	Status
E-2	Jan 1972	2,363.4	275.0	568,895	591,428	927, 928	Operational
E-12	Jan 1972	2,651.0	426.7	568,740	591,811	927, 928, Hidden	Operational
E-13	Jan 1972	2,863.7	217.6	568,595	592,104	927	Operational
L-21	Nov 1983	2,561.4	568.8*	568,774	591,696	927, Hidden	Operational
927 Rib							
E-1	Jan 1972	2,333.8	293.2	569,126	591,531	928, Hidden 930	Operational
E-9	Dec 1971	2,628.2	338.2	568,921	591,928	928, Hidden 930	Operational
E-10	Jan 1972	2,856.1	366.8	568,782	592,261	928, Hidden 930	Not operational
E-11	Dec 1971	3,207.3	387.7	568,511	592,847	928, Hidden	Sensors 0, 1, 2, 3, 6, 7, 8 not operational since Jan 1979
L-22	Nov 1983	2,569.5	509.1**	568,954	591,841	Hidden, 930	Operational

*Hole bears S69E down 4 degrees.
**Hole bears S68E down 3 degrees.

TABLE 4-7

925 AND 927 RIBS - SUMMARY OF PIEZOMETER OBSERVATIONS

Location	Piezometer No.	Sensor Elevation	Remarks
Near 927 Fault	PEP 6-4	2,785	Above pool - no head except for 30-foot peak in early 1972.
	PEP 6-3	2,747	Similar to 6-4.
	PEP 6-2	2,697	Similar to 6-4.
	PEP 6-1	2,671	Above pool - no head.
	PEP 2-4	2,490	Above pool - no head.
	PEP 20-6	2,457	Above pool - no head.
	PEP 20-5	2,412	Subdued response to pool.
	PEN 2-4	2,306	Became inoperative in 1972.
	PEN 2-3	2,267	Became inoperative in 1972.
Between 927 and 928	PEP 2-3	2,416	Follows behind and below pool - lag more pronounced after 1978.
	PEP 20-4	2,324	Generally follows pool - erratic after 1975.
	PEN 2-2	2,181	Became inoperative in 1972
Near 928 Fault	PEP 5-4	2,694	Above pool - no head.
	PEP 1-4	2,422	Lags behind pool cycle - occasional peaks above pool in 1972 and 1974.
	PEP 2-2 & 2A	2,331	Lags behind and below pool.
	PEP 20-3	2,274	Generally follows slightly below pool.
	PEN 1-4	2,271	Became inoperative in 1972.
	PEN 2-1	2,122	Became inoperative in 1972.
Near "Hidden" Fault	PEP 5-3	2,634	Above pool - has shown no head.
	PEP 5-2	2,584	Above pool - no head.
	PEP 1-3	2,391	Responds erratically to pools above 2,391.
	PEP 2-1 & 1A	2,248	Tends to lag behind pool.
	PEP 20-2B	2,181	Follows pool fairly well.
	PEP 20-2A	2,178	Followed slightly behind pool until 1977 when it became erratic.
	PEN 1-3	2,170	Became inoperative in 1972.
	PEN 1-2	2,142	Became inoperative in 1972.
Near 930 Fault	PEP 5-1	2,537	Above pool - has never shown any head.
	PEP 1-2 & 2A	2,331	Residual head at low pool dropped from 2,930 in 1974 to 2,360 in 1976. Piezometer 2A inoperative.
	PEP 1-1 & 1A	2,307	Residual head when pool below 2,390. Erratic in 1974 and 1975.
	PEP 20-1	2,098	Followed slightly behind pool until 1978 - inoperative.
	PEN 1-1	2,094	Became inoperative in 1972.

4.06 927 Rib.

a. Geology. The 927 Rib is defined by the S and T Joints, the latter forming the downstream side scarp of the Kootenai Narrows Slide. Three bedding faults, the 928, the Hidden, and the 930, segment the rib yielding three potential failure wedges. The 930 Bedding Fault is the basal failure plane on which the Kootenai Narrows slide failed. The plunge of the trough of intersection is 28 degrees toward the river. The major bedding faults are manifest as broad zones of many bedding faults, usually heavily weathered with scattered gouge and slickensides. There are numerous other bedding faults with gouge zones indicated in the subsurface. In addition to the normal slope wedge geometry of bedding faults and the east-west conjugate joints, a broad weak zone consisting of north-northwest joints is present between elevations 2,900 and 3,100 feet (between E-10 and E-11, plate 3) and provides the potential for separate failure of the upper part of the rib by "kicking out" into the old slide area.

b. Instrumentation. The 927 Rib is monitored by four SINCO-type vertical extensometers (E-1, E-9, E-10, and E-11, plate 3), three multistage piezometer installations, and a single inclinometer. All extensometers penetrate below the 930 Bedding Fault, though the fault could not be recognized in E-11 high on the slope. A Terrametrics-type 8-anchor MPBX (L-22) was installed at highway level in October 1983. Status of existing instruments is shown on tables 4-6 and 4-7.

c. Extensometer Analysis. On the 928 Bedding Fault, the shallowest of the three major faults in the rib, the small amount of borehole compression (E-1-7) in mid-1972 may be either downslope movement or actual consolidation due to construction activity (figure 4.15a). No further activity is noted. The Hidden Bedding Fault showed a minimal compression at the toe, accumulating mostly in 1973 (figure 4.18b), but has been stable since. The 930 Bedding Fault exhibited stability until late in 1981. The two lower sensors of E-1 (E-1-1 and E-1-2, see appendix C), the latter of which crosses the Hidden Bedding Fault, showed extension on the order of 0.08 to 0.18 inch at this time, while the totalizer (E-1-0) showed compression on the order of 0.05 inch. The opposing reaction appears to be an instrumental problem, casting some question on viability of further data from the instrument. Early in 1981, E-1-8 showed compression on the order of 0.04 inch, indicative of downslope movement of a surficial block. This movement was not directly substantiated by the totalizer which may no longer be a viable sensor. The most well documented motion in this rib was during the period 1973 to 1976, beginning with the second pool rise, when the near surface sensor at the toe of the rib, E-1-8, indicated compression on the order of 0.3 inch, suggesting a downslope slip on a shallow, unnamed bedding fault of about 0.6 inch (appendix C, E-1 plots). No further evidence of slippage was noted after the 1976 pool rise. Seasonal cyclic motion in response to ambient temperature changes in the surficial rock mass high on the slope is seen on both E-10 and E-11.

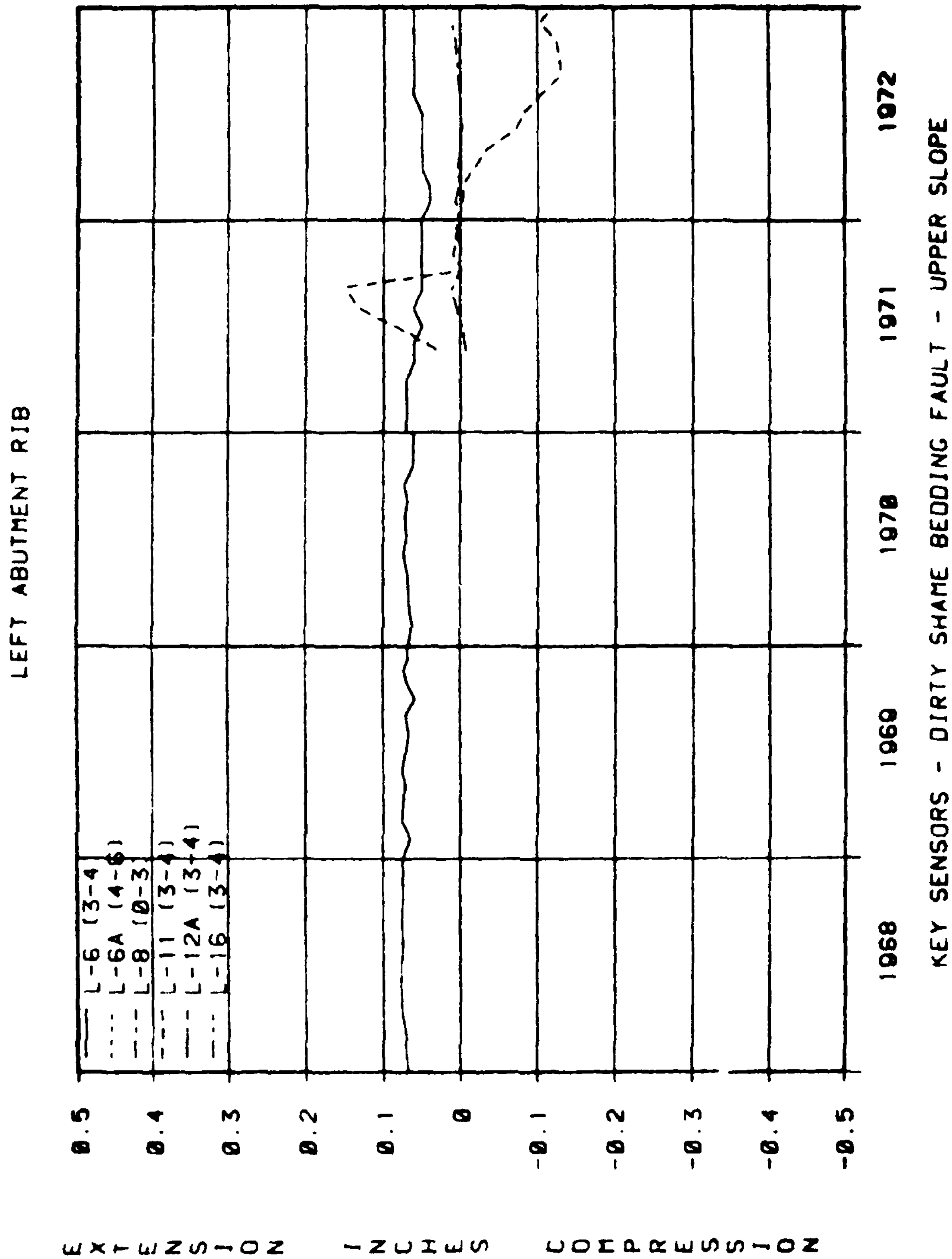
d. Piezometer Analysis. Plots of piezometer data are shown in appendix D. A summary of piezometer observations is presented in table 4-7. In general, piezometers located below elevation 2,459 feet respond to pool fluctuations with little or no time lag. A few piezometers have exhibited residual head where the pool drops below the piezometer elevation. The most significant of these are as follows:

Location	Piezometer No.	Remarks
930 Fault	PP-1-1	Fairly consistent residual head at pools below elevation 2,330 feet (up to 85-foot head).
	PEP-1-2	Residual head has dropped from about elevation 2,390 feet in 1974 (60-foot head) to elevation 2,365 feet (35-foot head) since 1978.

Except for the above, most data indicates that rock is free draining for the pool drawdown rates experienced. The exceptions noted are not believed to be very significant considering the magnitude of residual head and the presence of the buttress fill.

e. Inclinometer Analysis. No detectable movement has been recognized on NI-1.

f. Conclusion. Other than the anomalous instrumental motion shown at the toe on the 930 Bedding Fault, there are no indications of movement or adjustment in this rib.



LEFT ABUTMENT RIB
KEY SENSORS - DIRTY SHAME BEDDING FAULT - UPPER SLOPE
L-6 (3-4
L-6A (4-6)
L-8 (0-3)
L-11 (3-4)
L-12A (3-4)
L-16 (3-4)
1968
1969
1970
1971
1972
0.5
0.4
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
-0.4
-0.5
EXTENSION
INCHES
COMPRESSION

Fig. 4.3a

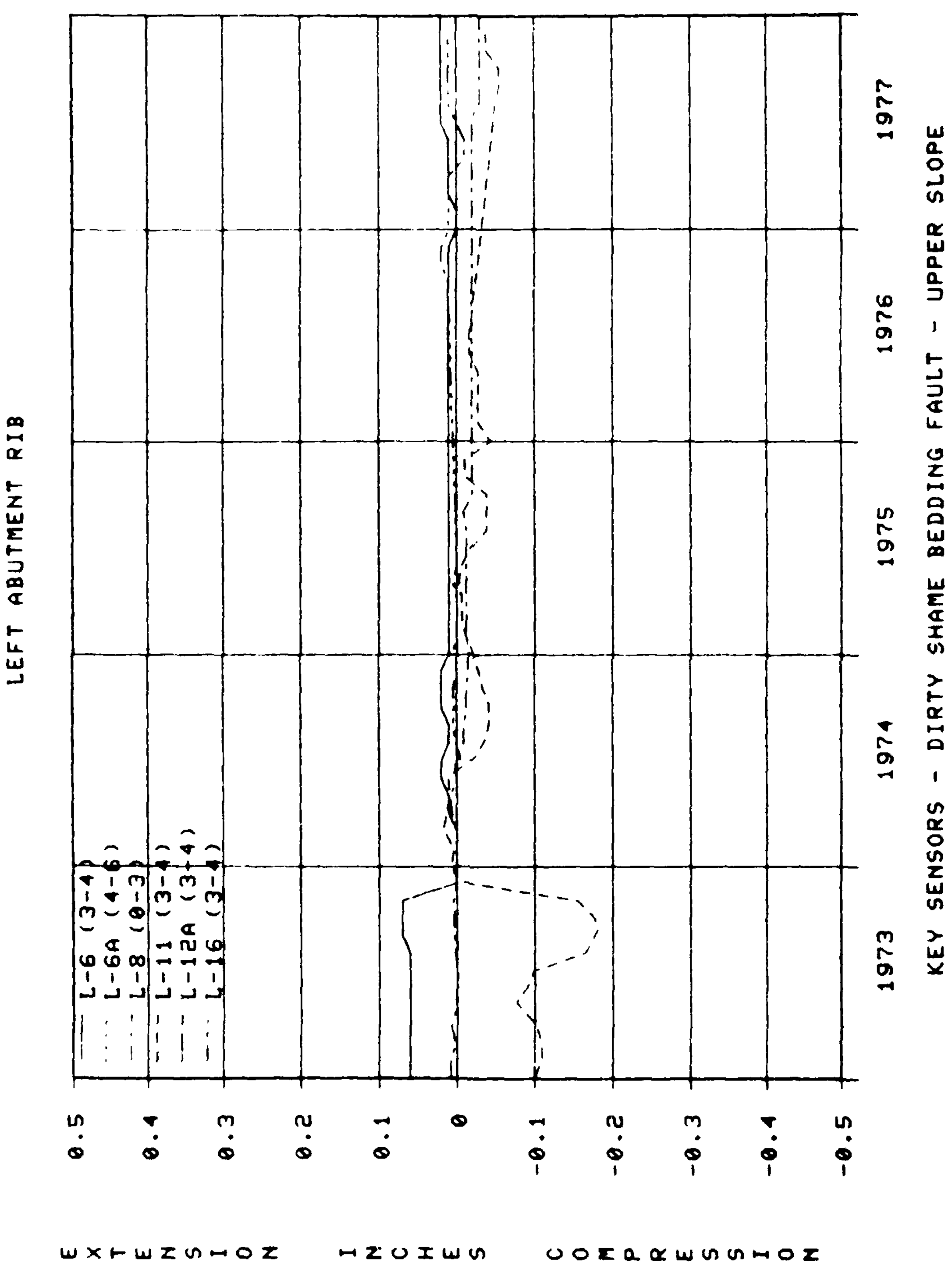
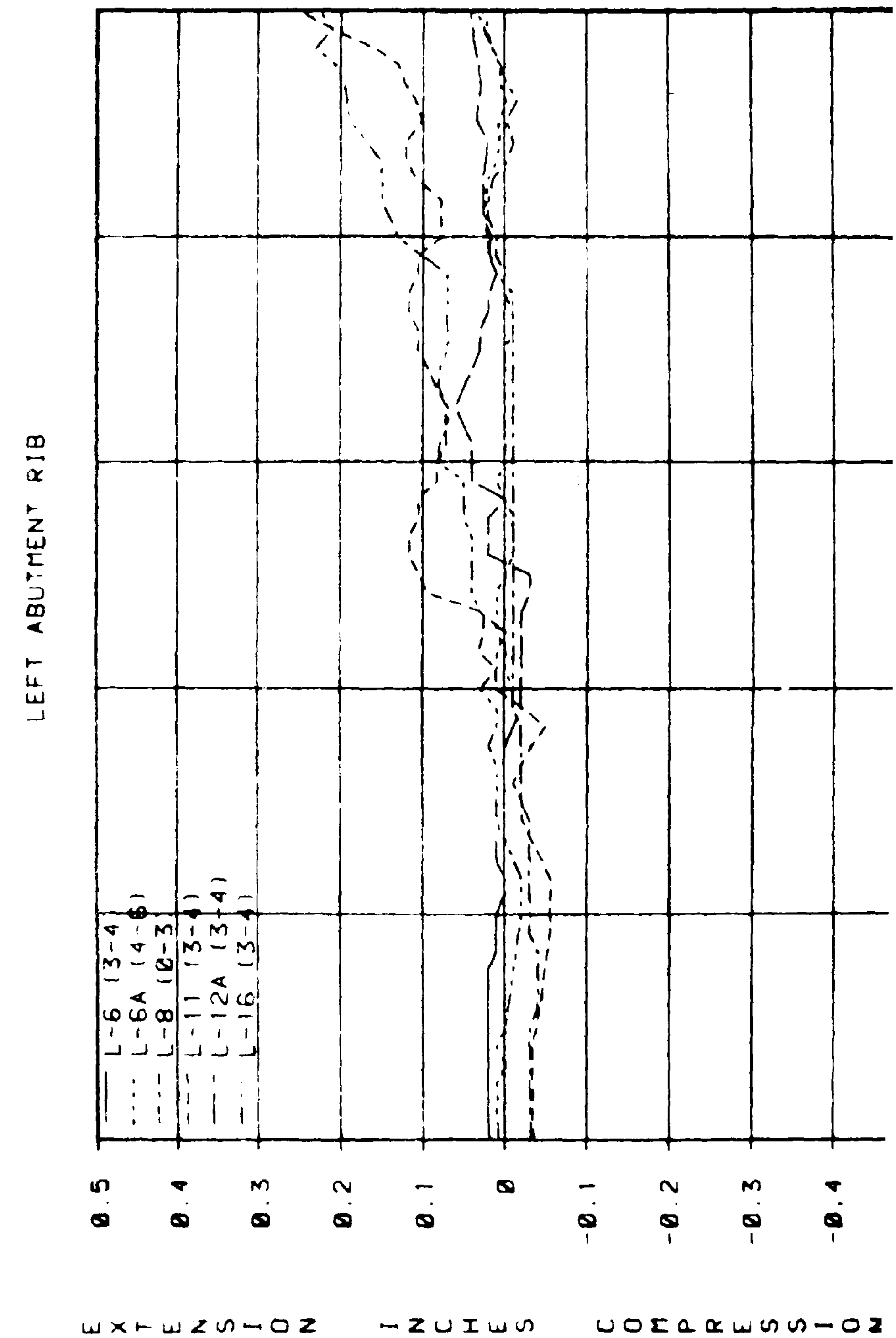
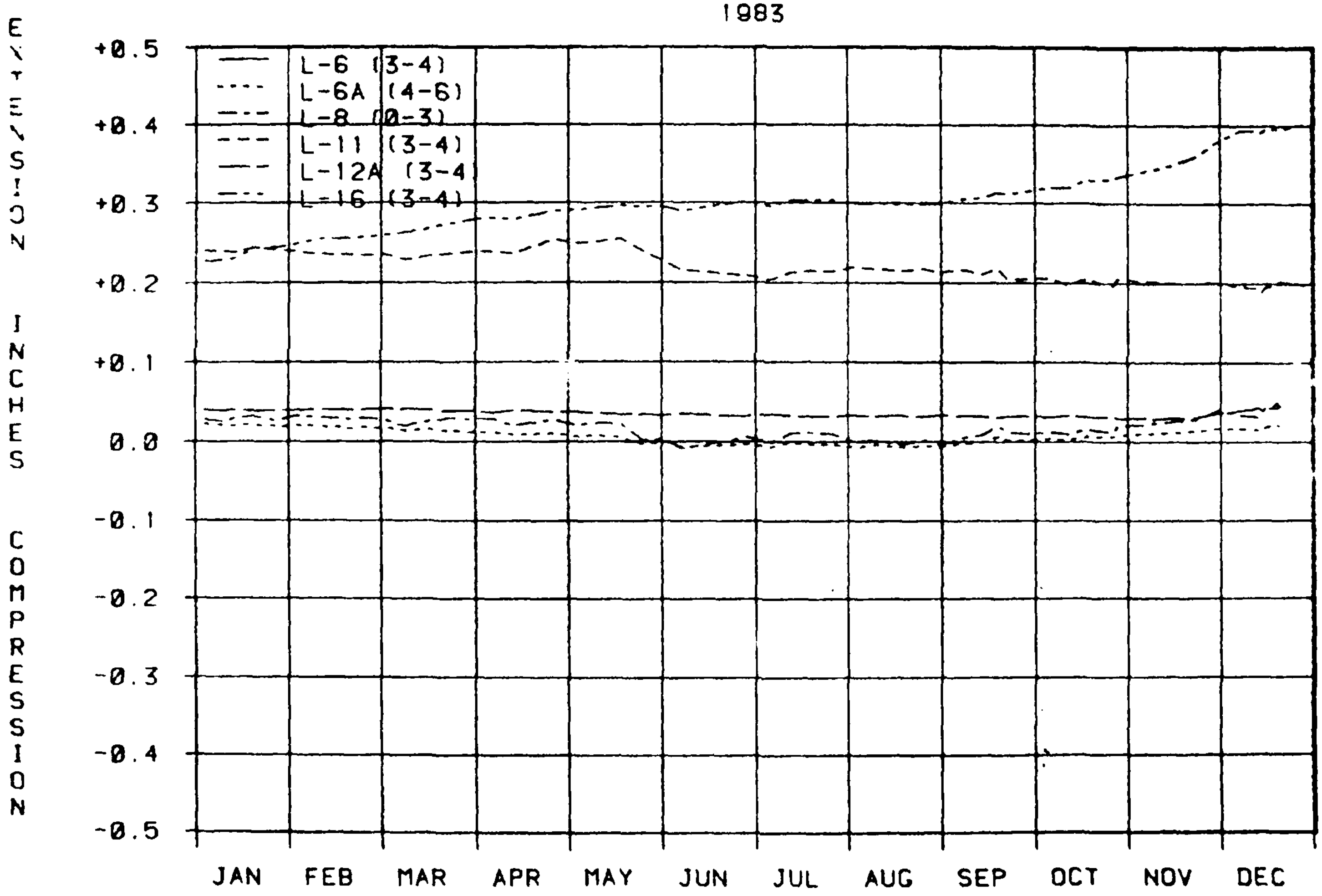

LEFT ABUTMENT RIB
L-6 (3-4)
L-6A (4-6)
L-8 (0-3)
L-11 (3-4)
L-12A (3-4)
L-16 (3-4)
0.5
0.4
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
-0.4
-0.5
EXTENSION INCHES COMPRESSION
1973
1974
1975
1976
1977
KEY SENSORS - DIRTY SHAME BEDDING FAULT - UPPER SLOPE

Fig. 4.3b


LEFT ABUTMENT RIB
L-6 (3-4)
L-6A (4-6)
L-8 (0-3)
L-11 (3-4)
L-12A (3-4)
L-16 (3-4)
0.5
0.4
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
-0.4
EXTENSION
INCHES
COMPRESSION

LEFT ABUTMENT RIB
1983



KEY SENSORS - DIRTY SHAME BEDDING FAULT - UPPER SLOPE

Fig

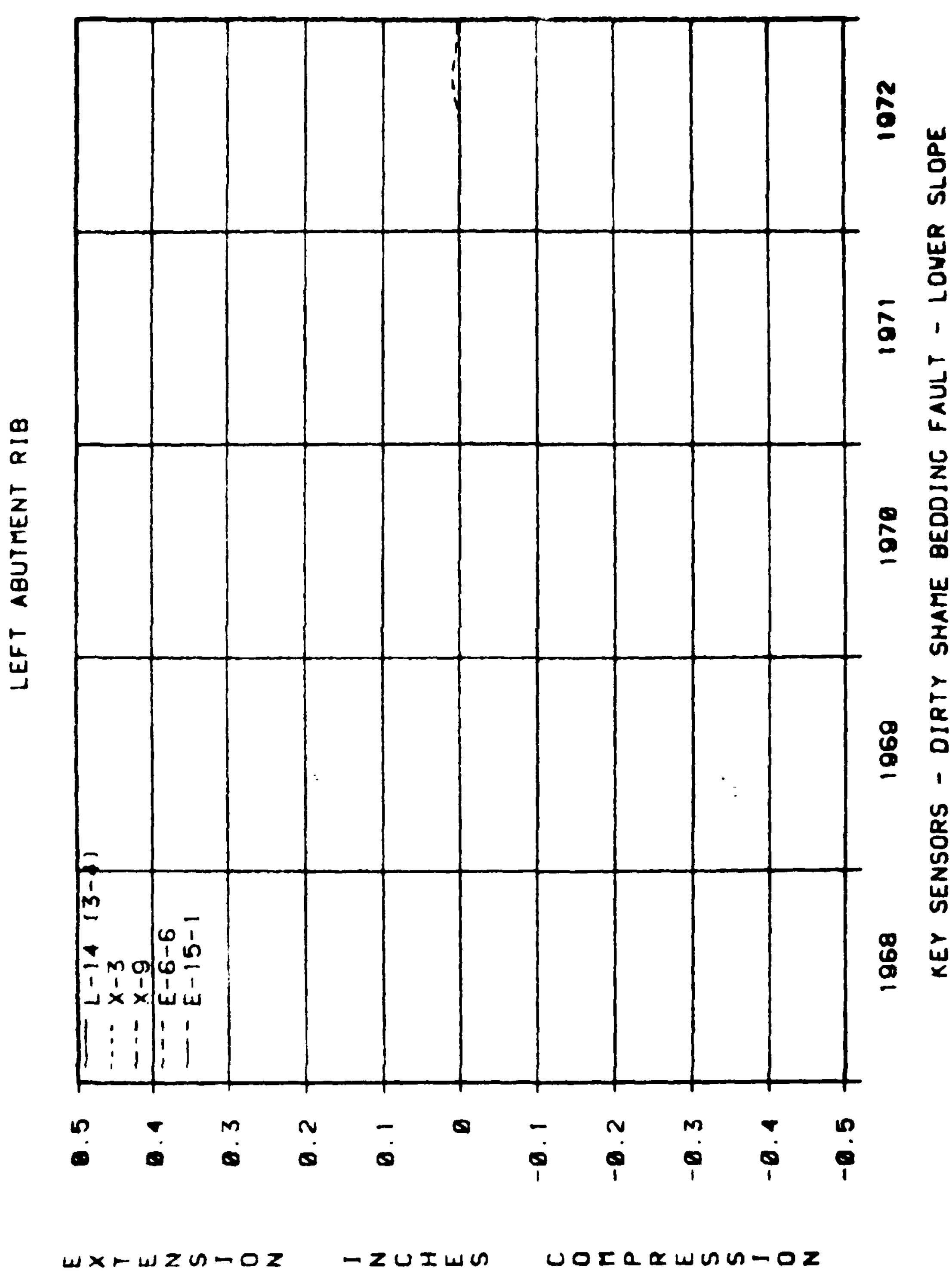
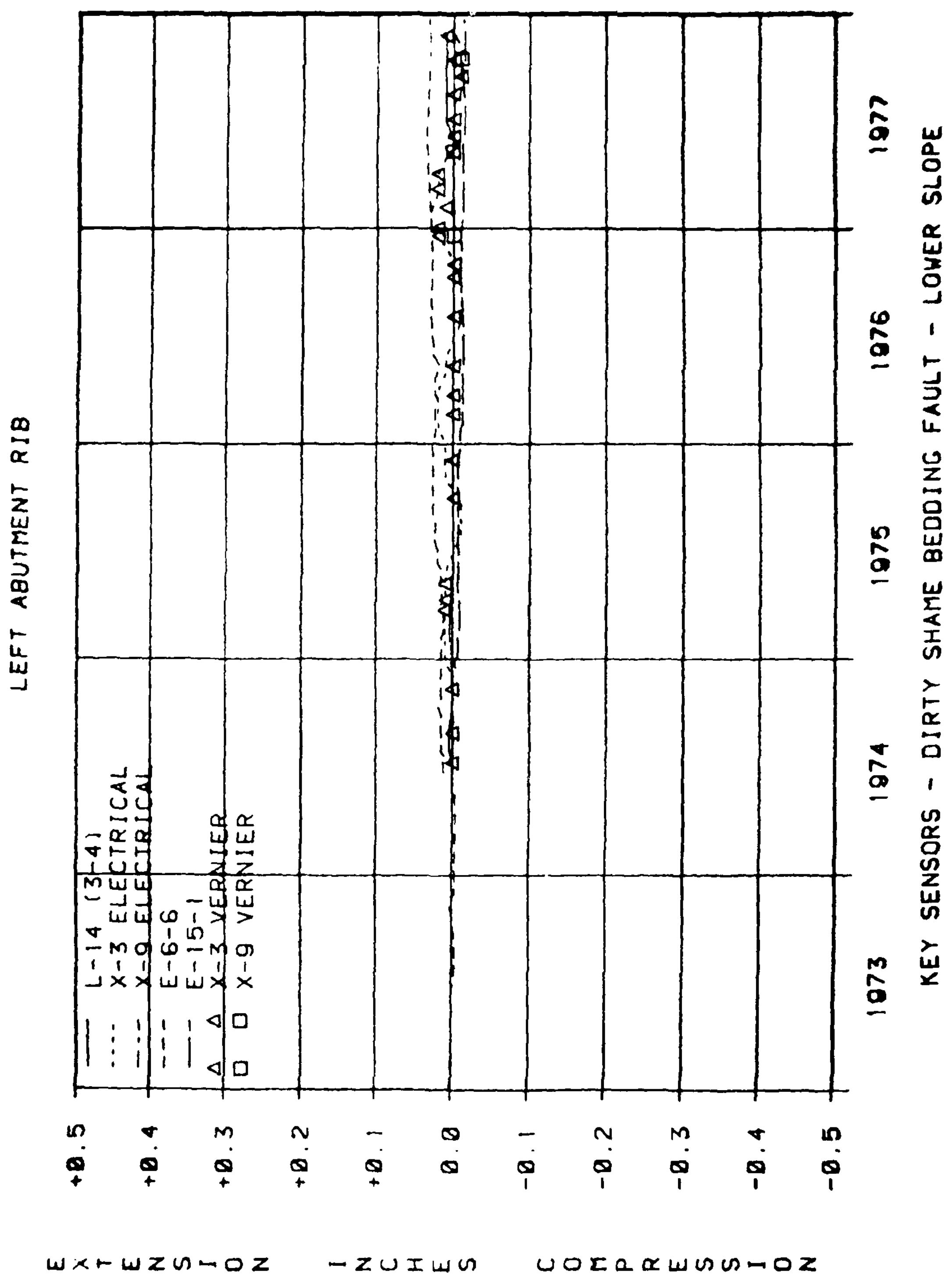

LEFT ABUTMENT RIB
KEY SENSORS - DIRTY SHAME BEDDING FAULT - LOWER SLOPE
1968
1969
1970
1971
1972
0.5
0.4
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
-0.4
-0.5
EXTENSION INCHES COMPRESSION
L-14 (3-
X-3
X-9
E-6-6
E-15-1

Fig. 4.4a



LEFT ABUTMENT RIB
L-14 (3-4)
X-3 ELECTRICAL
X-9 ELECTRICAL
E-6-6
E-15-1
X-3 VERNIER
X-9 VERNIER
+0.5
+0.4
+0.3
+0.2
+0.1
0.0
-0.1
-0.2
-0.3
-0.4
-0.5
EXTENSION INCHES COMPRESSION
1973
1974
1975
1976
1977
KEY SENSORS - DIRTY SHAME BEDDING FAULT - LOWER SLOPE

Fig. 4.4b

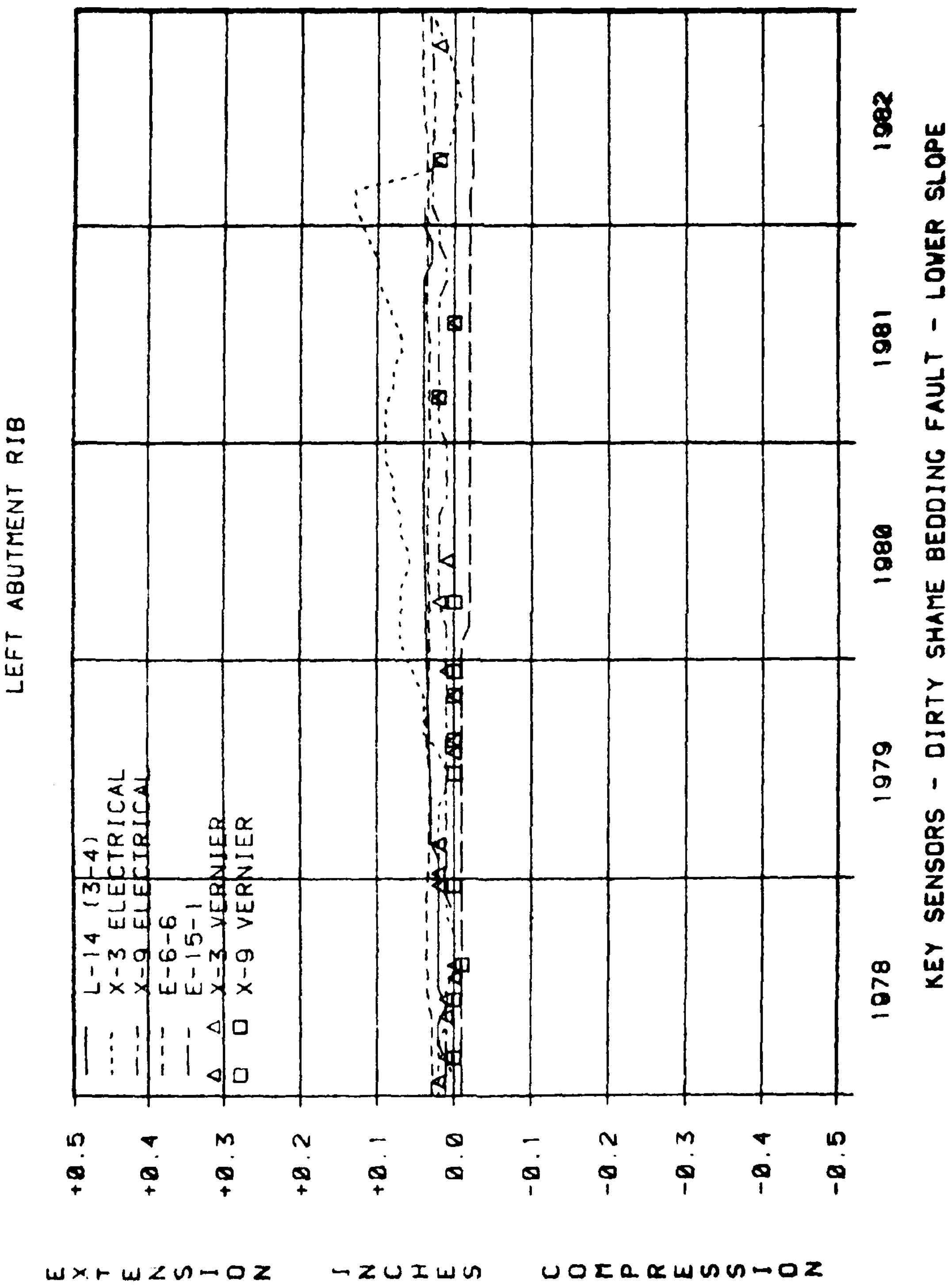

LEFT ABUTMENT RIB
L-14 (3-4)
X-3 ELECTRICAL
X-9 ELECTRICAL
E-6-6
E-15-1
X-3 VERNIER
X-9 VERNIER
+0.5
+0.4
+0.3
+0.2
+0.1
0.0
-0.1
-0.2
-0.3
-0.4
-0.5
EXTENSION
INCHES
COMPRESSION
1978
1979
1980
1981
1982
KEY SENSORS - DIRTY SHAME BEDDING FAULT - LOWER SLOPE

Fig. 4.4c

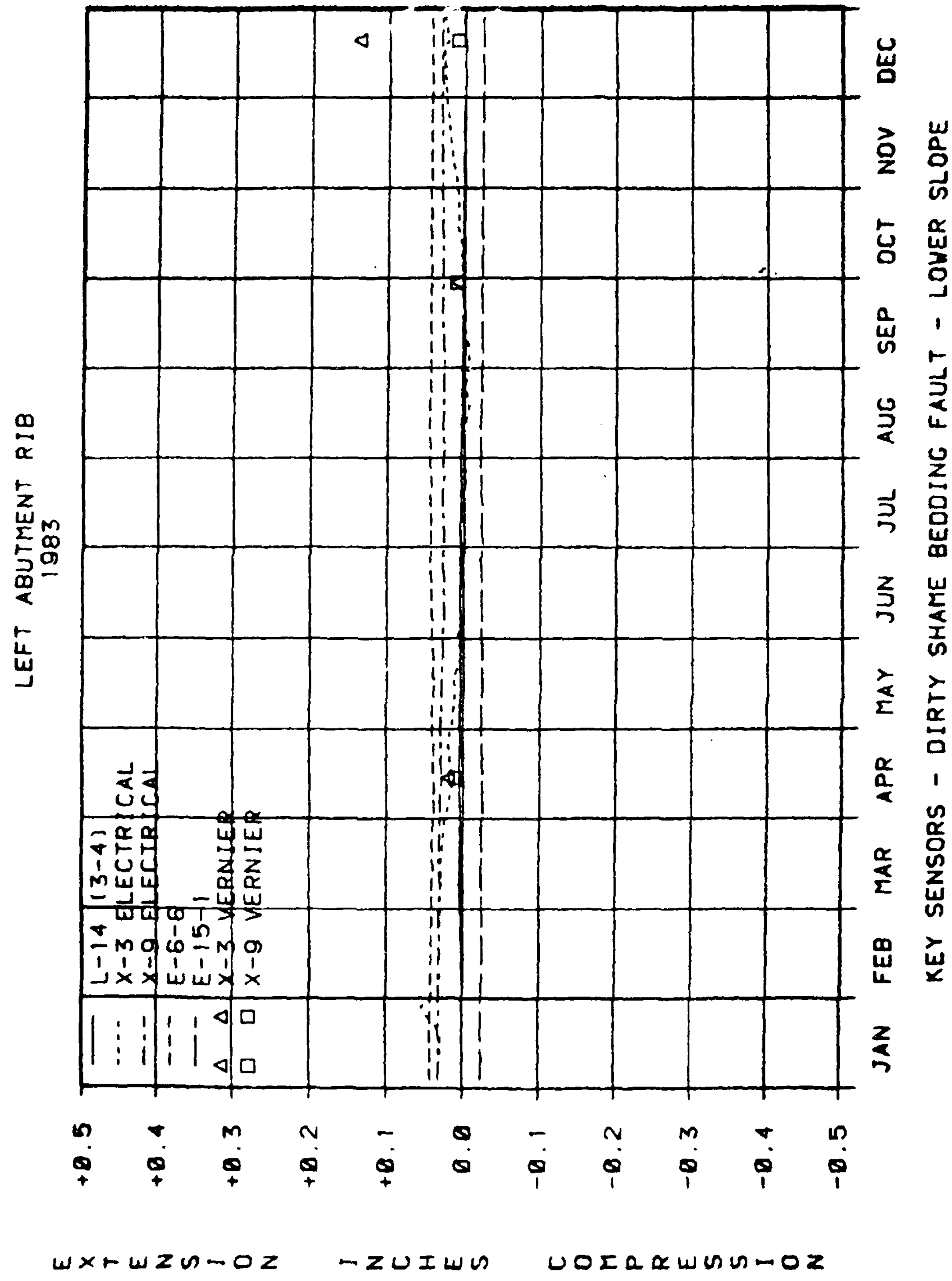
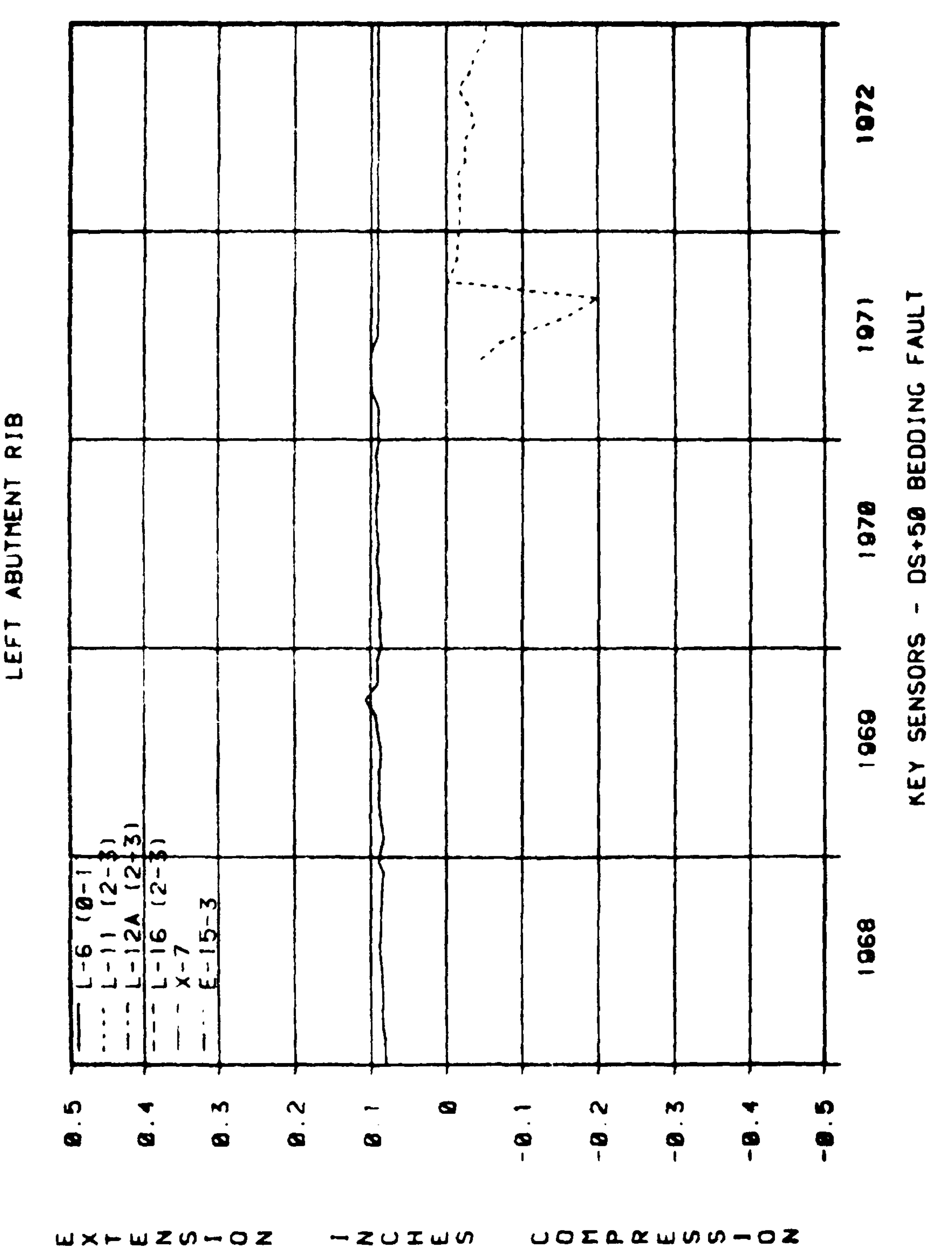
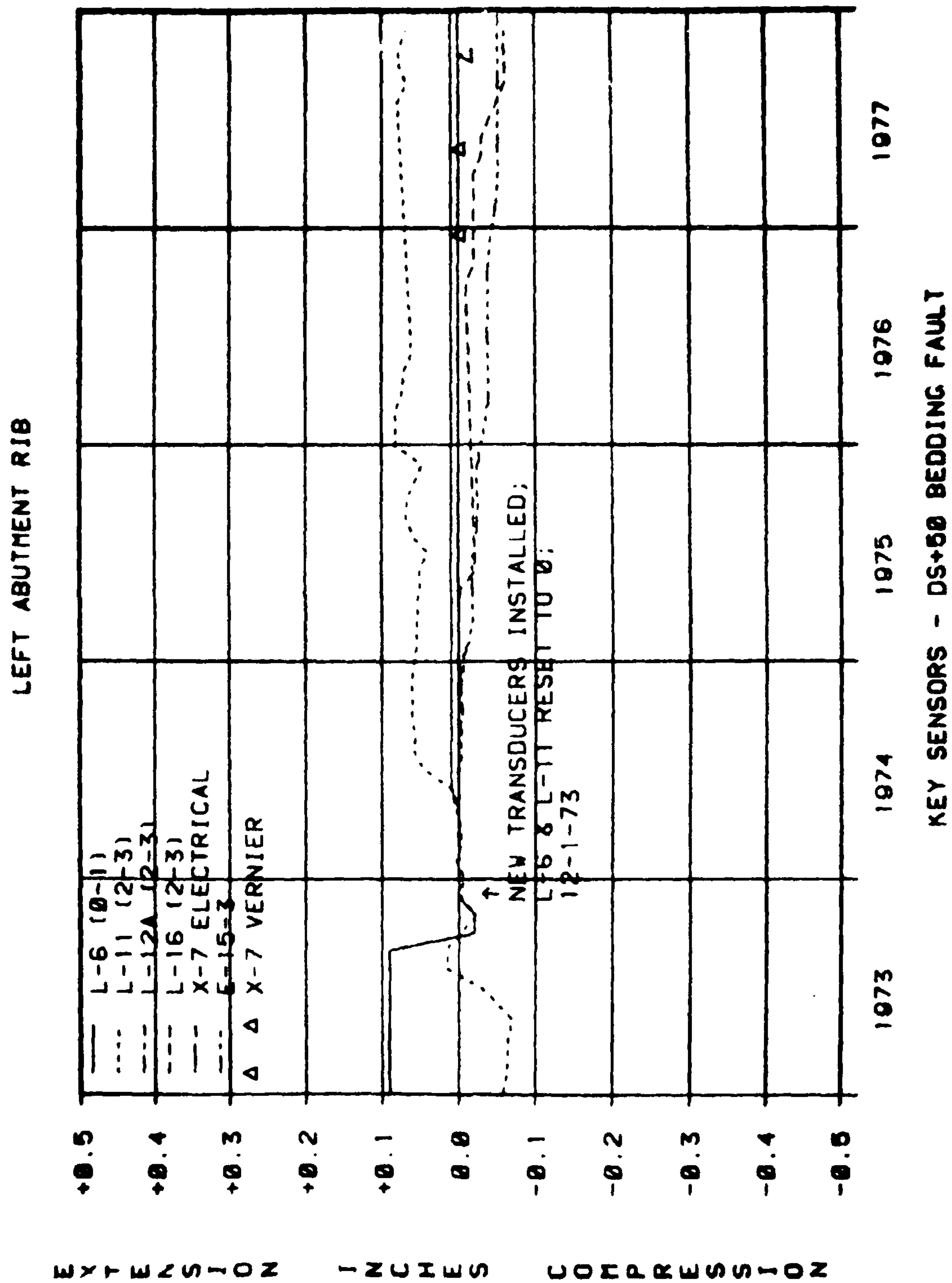

LEFT ABUTMENT RIB
1983
L-14 (3-4)
X-3 ELECTRICAL
X-9 ELECTRICAL
E-6-6
E-15-1
X-3 VERNIER
X-9 VERNIER
JAN FEB MAR APR MAY JUN JUL AUG SEP OCT NOV DEC
+0.5 +0.4 +0.3 +0.2 +0.1 0.0 -0.1 -0.2 -0.3 -0.4 -0.5
EXTENSION INCHES COMPRESSION
KEY SENSORS - DIRTY SHAME BEDDING FAULT - LOWER SLOPE

Fig. 4.4d



LEFT ABUTMENT RIB
KEY SENSORS - DS+50 BEDDING FAULT
L-6 (0-1)
L-11 (2-3)
L-12A (2-3)
L-16 (2-3)
X-7
E-15-3
1968
1969
1970
1971
1972
0.5
0.4
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
-0.4
-0.5
EXTENSION
INCHES
COMPRESSION

Fig. 4.5a



LEFT ABUTMENT RIB
KEY SENSORS - DS+50 BEDDING FAULT
L-6 (0-1)
L-11 (2-3)
L-12A (2-3)
L-16 (2-3)
X-7 ELECTRICAL
E-15-3
X-7 VERNIER
NEW TRANSDUCERS INSTALLED;
L-6 & L-11 RESET TO 0;
12-1-73
+0.5
+0.4
+0.3
+0.2
+0.1
0.0
-0.1
-0.2
-0.3
-0.4
-0.5
EXTENSION
INCHES
COMPRESSION
1973
1974
1975
1976
1977

Fig. 4.5b

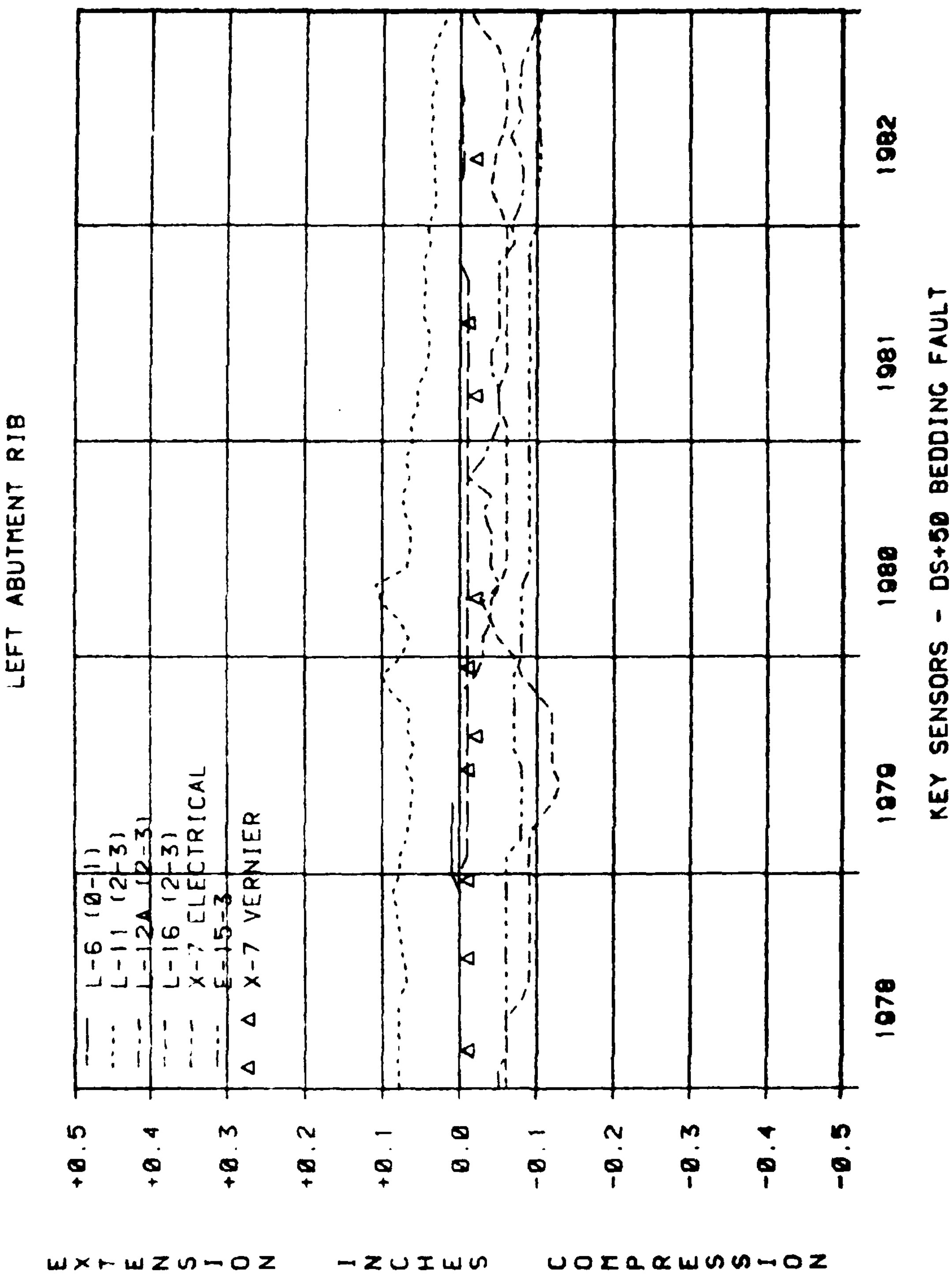

LEFT ABUTMENT RIB
KEY SENSORS - DS+50 BEDDING FAULT
L-6 (0-1)
L-11 (2-3)
L-12A (2-3)
L-16 (2-3)
X-7 ELECTRICAL
E-15-3
X-7 VERNIER
1978
1979
1980
1981
1982
+0.5
+0.4
+0.3
+0.2
+0.1
0.0
-0.1
-0.2
-0.3
-0.4
-0.5
EXTENSION INCHES COMPRESSION

Fig. 4.5c

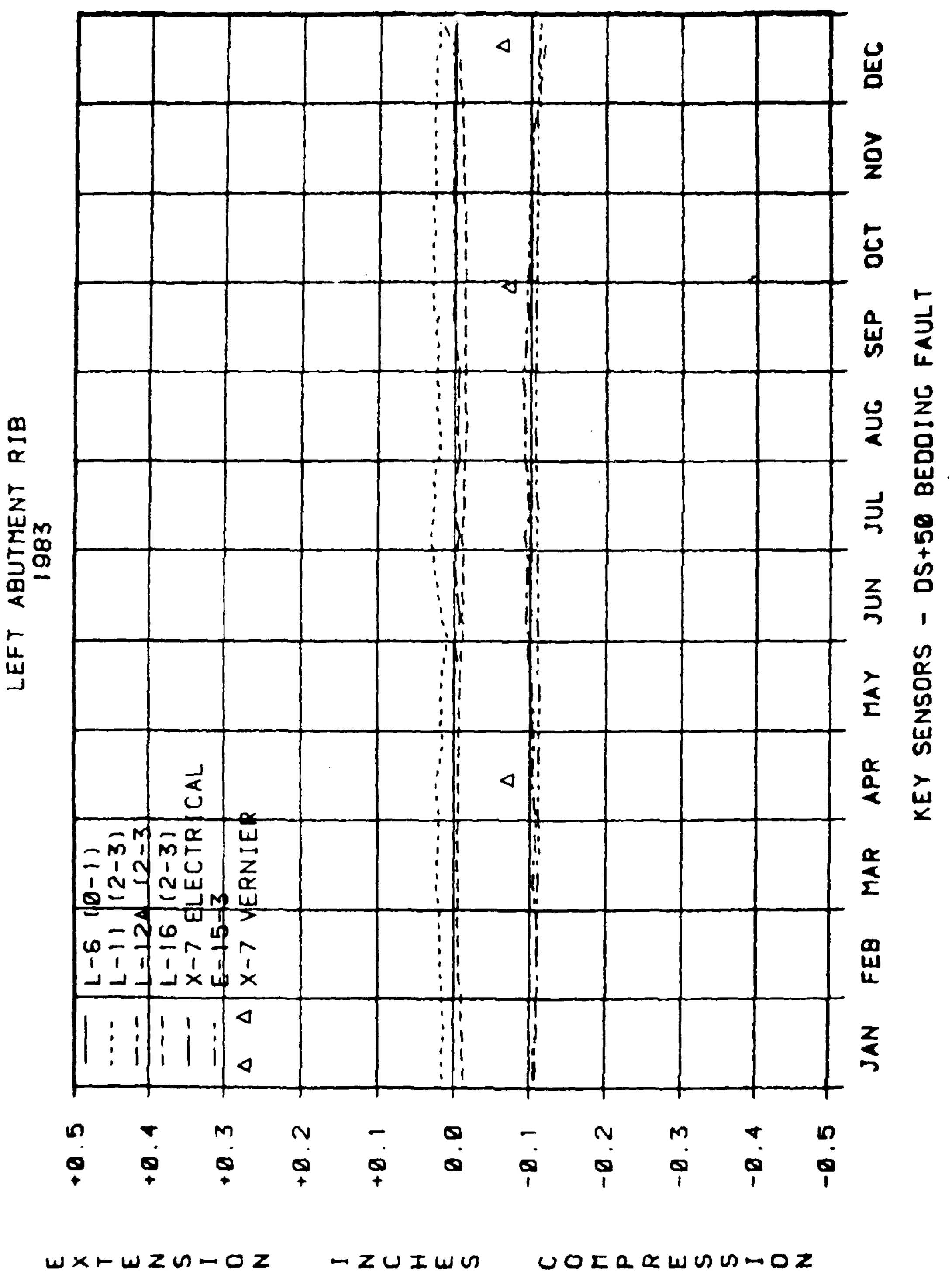
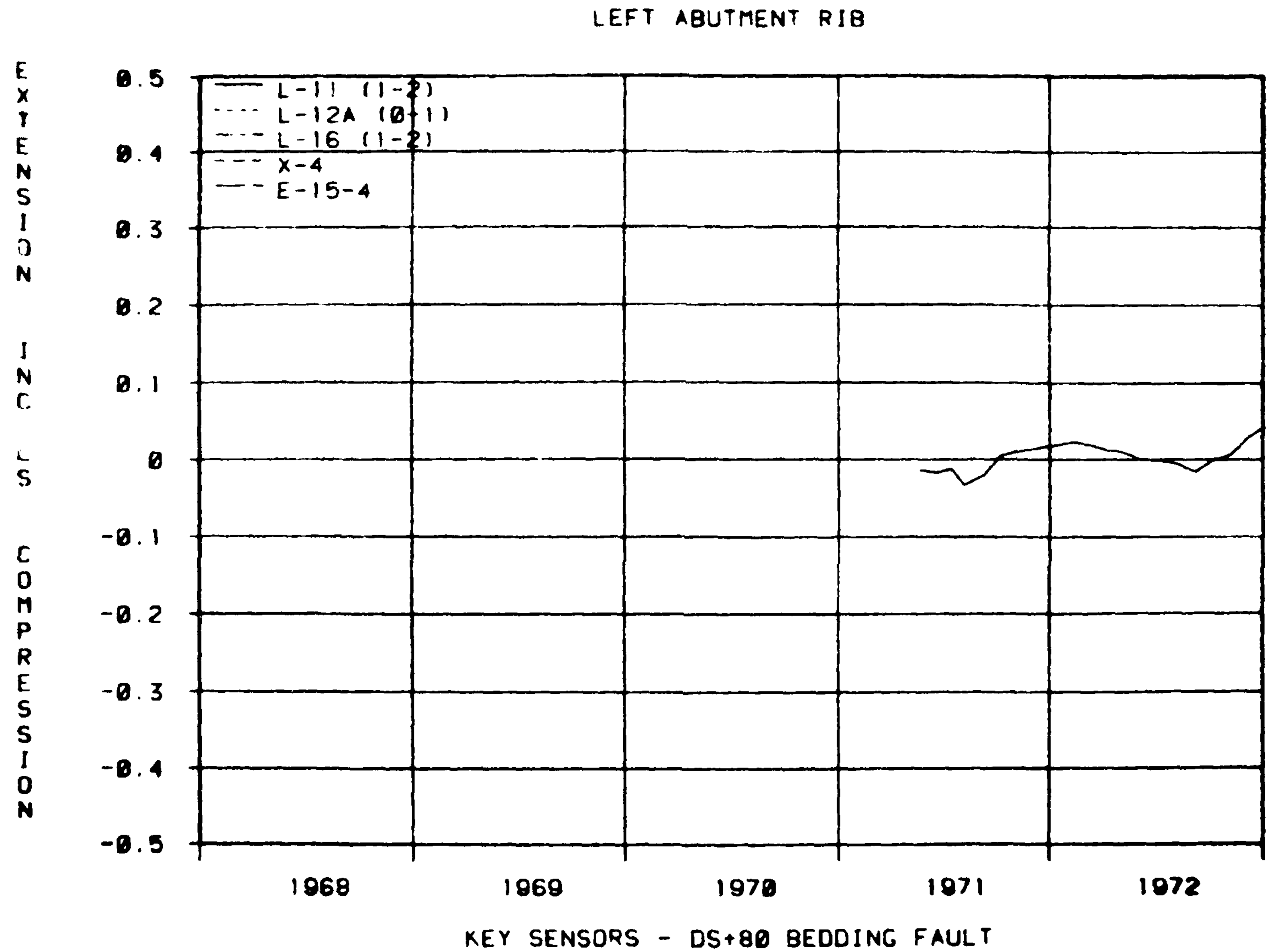
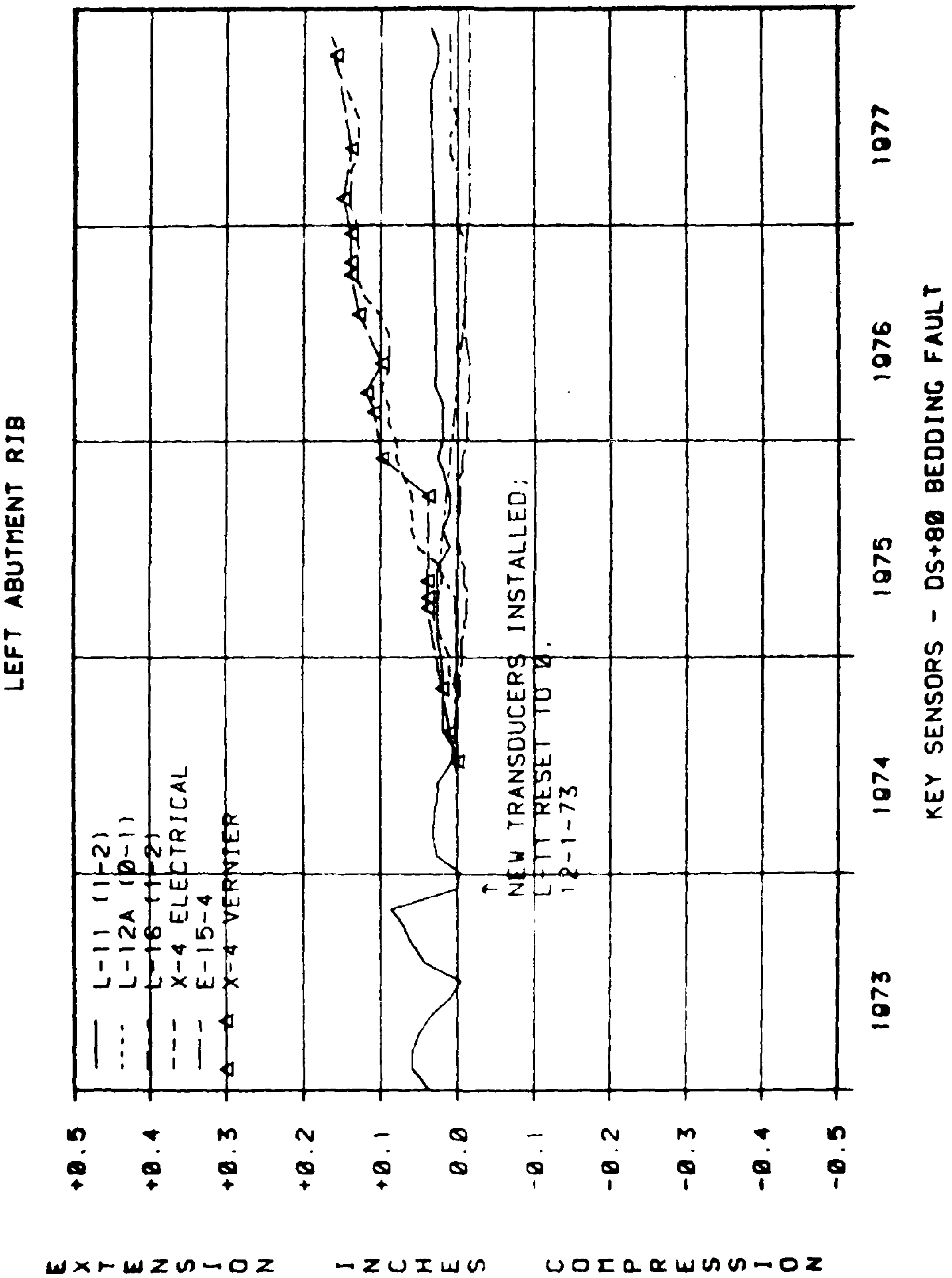

LEFT ABUTMENT RIB
1983
L-6 (0-1)
L-11 (2-3)
L-12A (2-3)
L-16 (2-3)
X-7 ELECTRICAL
E-15-3
X-7 VERNIER
JAN FEB MAR APR MAY JUN JUL AUG SEP OCT NOV DEC
KEY SENSORS - DS+50 BEDDING FAULT
+0.5 +0.4 +0.3 +0.2 +0.1 0.0 -0.1 -0.2 -0.3 -0.4 -0.5
EXTENSION INCHES COMPRESSION

Fig 4.5d


LEFT ABUTMENT RIB
EXTENSION IN. CS COMPRESSION
0.5
0.4
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
-0.4
-0.5
L-11 (1-2)
L-12A (0-1)
L-16 (1-2)
X-4
E-15-4
1968
1969
1970
1971
1972
KEY SENSORS - DS+80 BEDDING FAULT

71

Fig. 4.6a



LEFT ABUTMENT RIB
KEY SENSORS - DS+80 BEDDING FAULT
L-11 (1-2)
L-12A (0-1)
L-16 (1-2)
X-4 ELECTRICAL
E-15-4
X-4 VERNIER
NEW TRANSDUCERS INSTALLED;
L-11 RESET TO 0.
12-1-73
1973
1974
1975
1976
1977
+0.5
+0.4
+0.3
+0.2
+0.1
0.0
-0.1
-0.2
-0.3
-0.4
-0.5
EXTENSION INCHES COMPRESSION

Fig. 4.6b

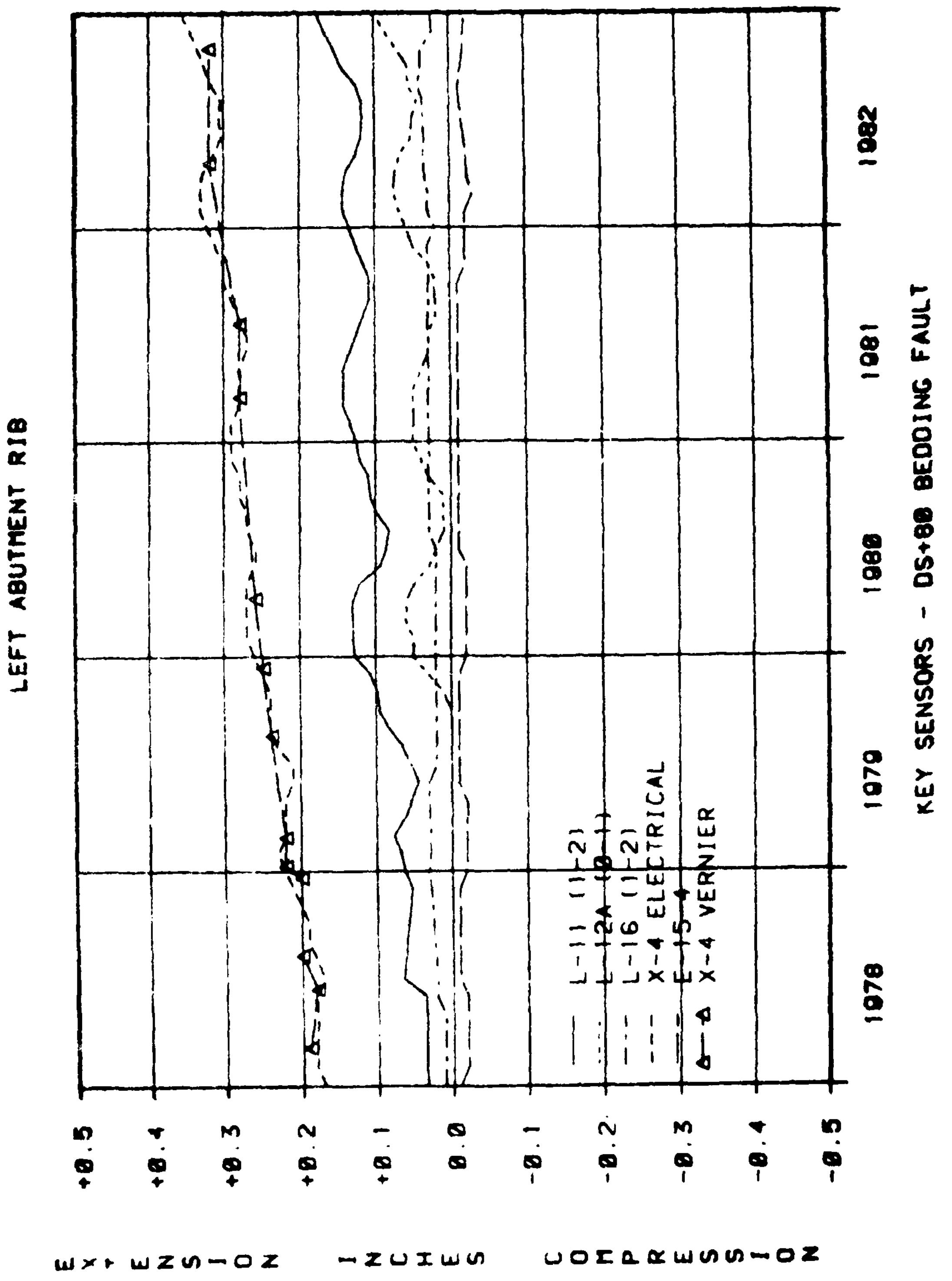
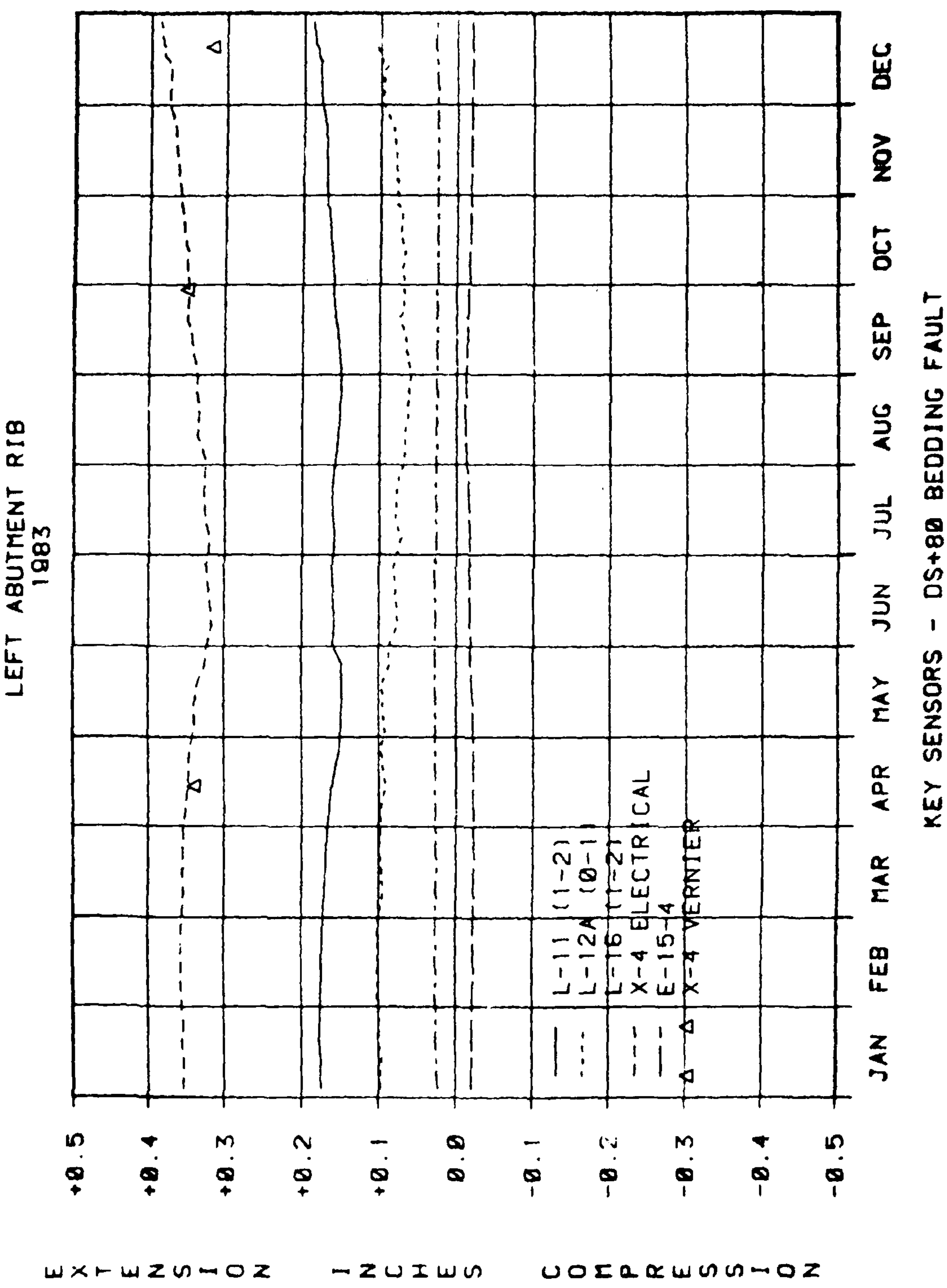
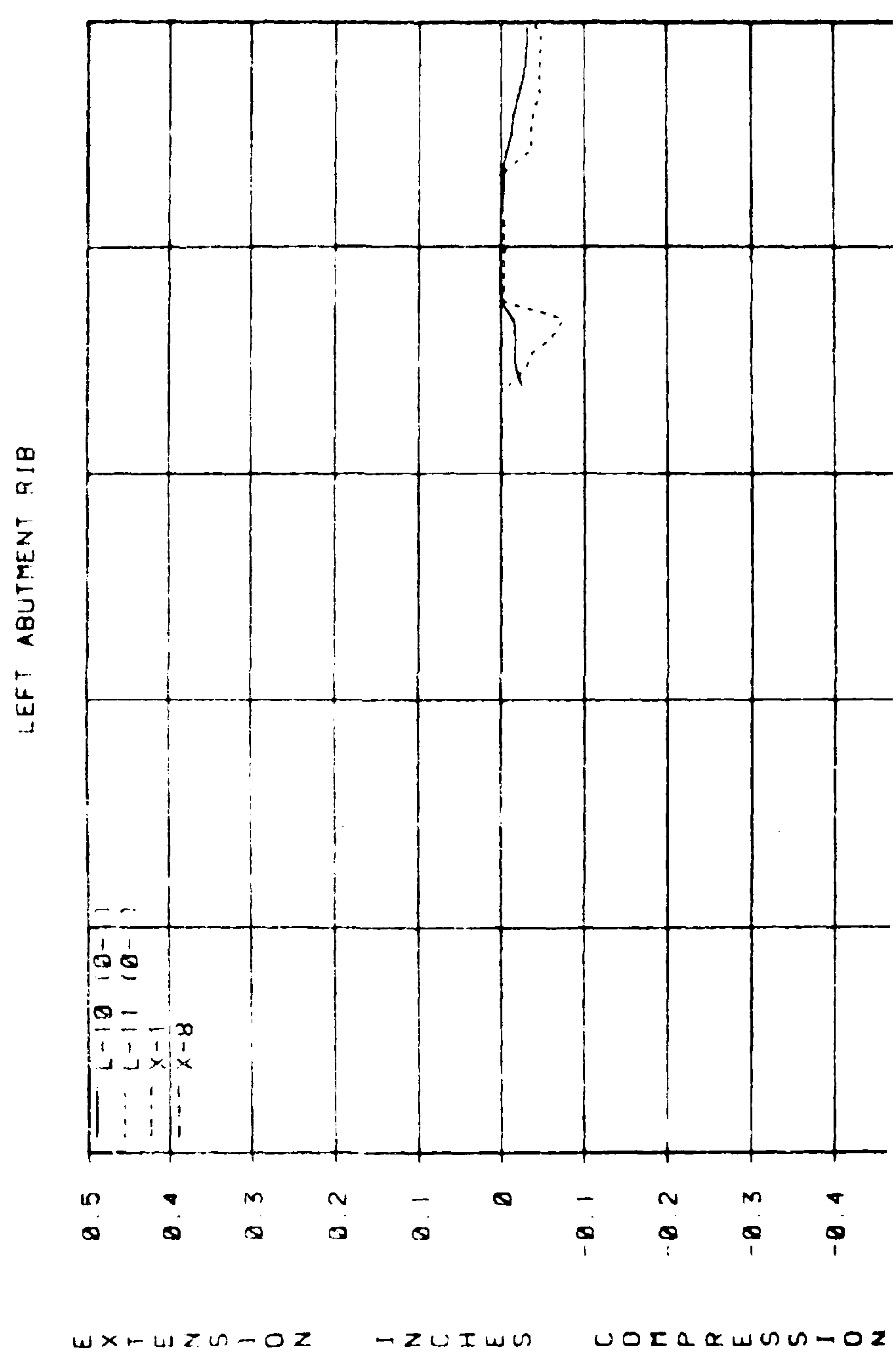

LEFT ABUTMENT RIB
KEY SENSORS - DS+80 BEDDING FAULT
1978
1979
1980
1981
1982
+0.5
+0.4
+0.3
+0.2
+0.1
0.0
-0.1
-0.2
-0.3
-0.4
-0.5
EXTENSION INCHES COMPRESSION
L-11 (1-2)
L-12A (0-1)
L-16 (1-2)
X-4 ELECTRICAL
E-15-4
X-4 VERNIER

Fig. 4.6c

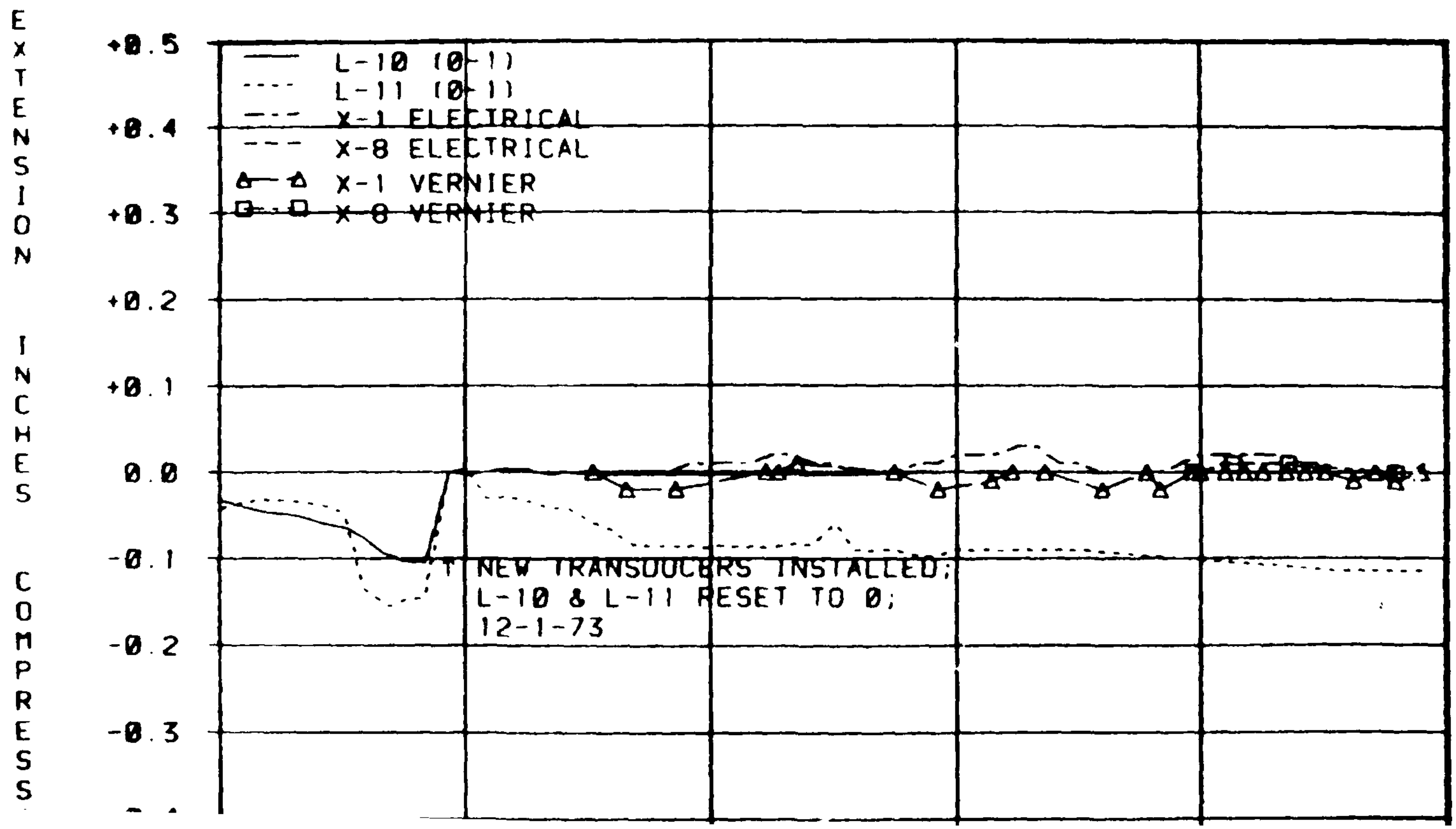


LEFT ABUTMENT RIB
1983
KEY SENSORS - DS+80 BEDDING FAULT
JAN FEB MAR APR MAY JUN JUL AUG SEP OCT NOV DEC
+0.5 +0.4 +0.3 +0.2 +0.1 0.0 -0.1 -0.2 -0.3 -0.4 -0.5
EXTENSION INCHES COMPRESSION
L-11 (1-2)
L-12A (0-1)
L-16 (1-2)
X-4 ELECTRICAL
E-15-4
X-4 VERNIER

Fig 4.6d


LEFT ABUTMENT RIB
L-10 (0-1)
L-11 (0-1)
X-1
X-8
0.5
0.4
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
-0.4
EXTENSION INCHES COMPRESSION

LEFT ABUTMENT RIB



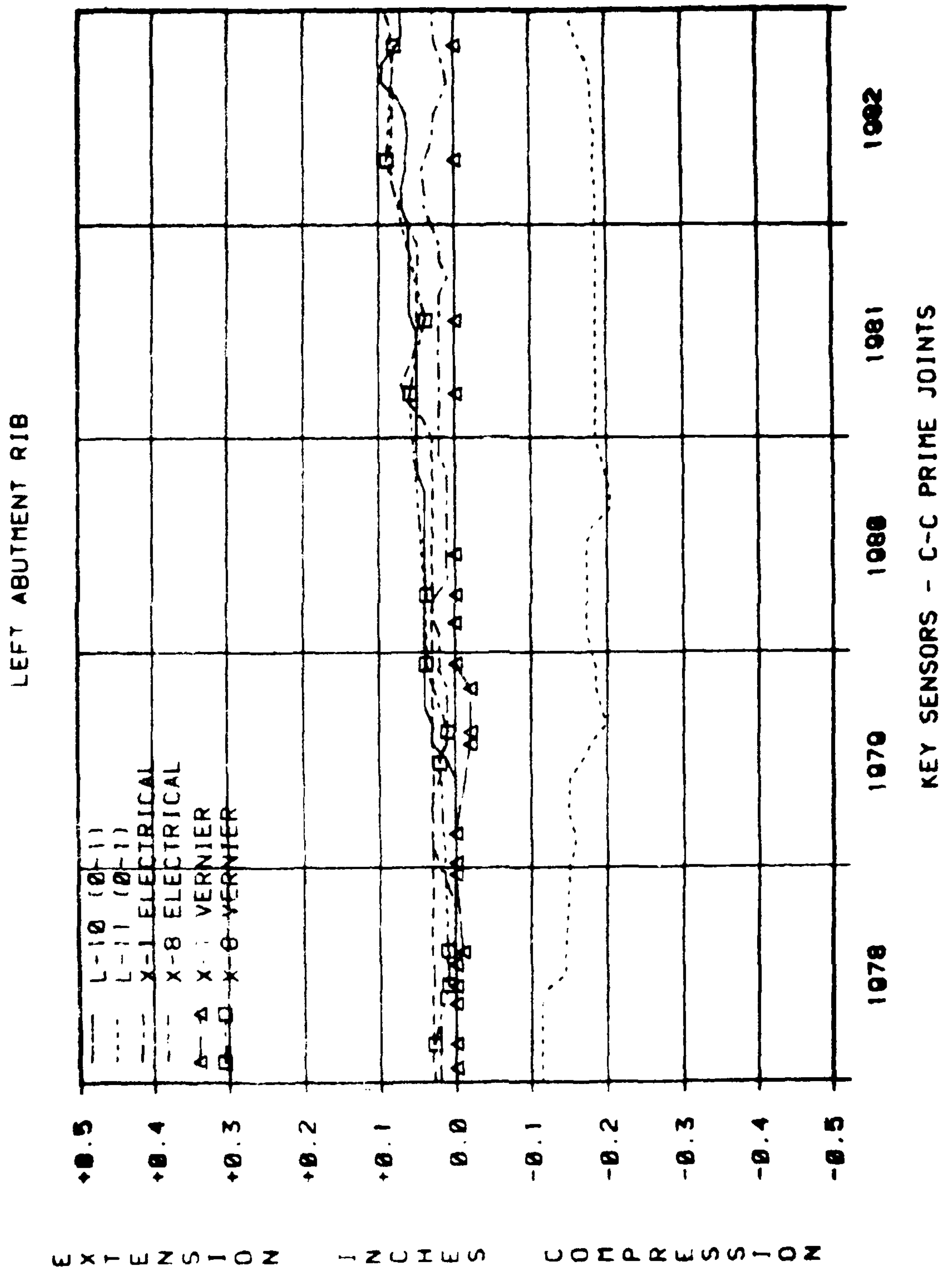

LEFT ABUTMENT RIB
L-10 (0-1)
L-11 (0-1)
X-1 ELECTRICAL
X-8 ELECTRICAL
X-1 VERNIER
X-8 VERNIER
+0.5
+0.4
+0.3
+0.2
+0.1
0.0
-0.1
-0.2
-0.3
-0.4
-0.5
EXTENSION
INCHES
COMPRESSION
1978
1979
1980
1981
1982
KEY SENSORS - C-C PRIME JOINTS

Fig. 4.7c

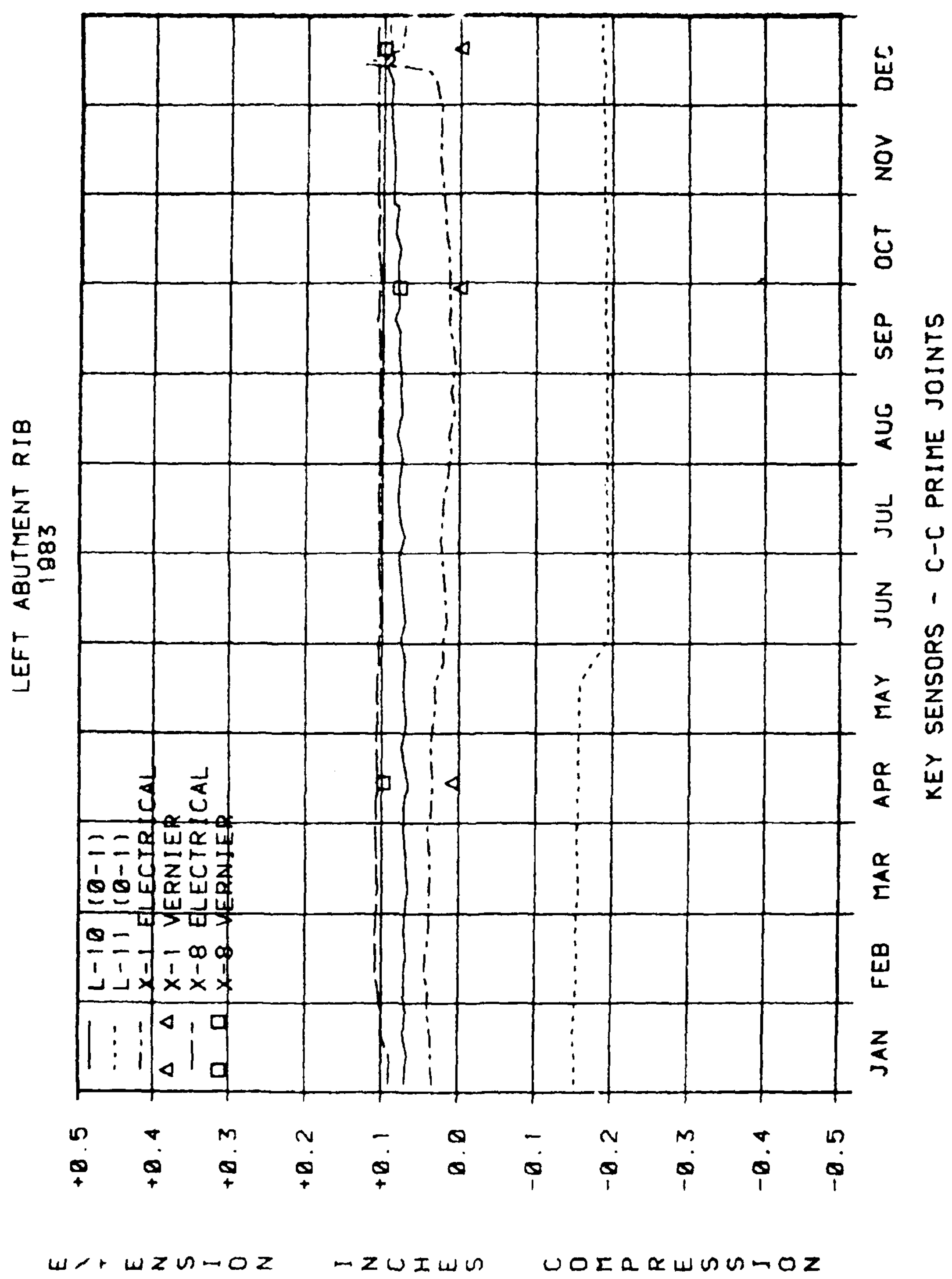

LEFT ABUTMENT RIB
1983
L-10 (0-1)
L-11 (0-1)
X-1 ELECTRICAL
X-1 VERNIER
X-8 ELECTRICAL
X-8 VERNIER
+0.5
+0.4
+0.3
+0.2
+0.1
0.0
-0.1
-0.2
-0.3
-0.4
-0.5
JAN FEB MAR APR MAY JUN JUL AUG SEP OCT NOV DEC
KEY SENSORS - C-C PRIME JOINTS
INCHES
COMPRESSION

Fig 4.7d

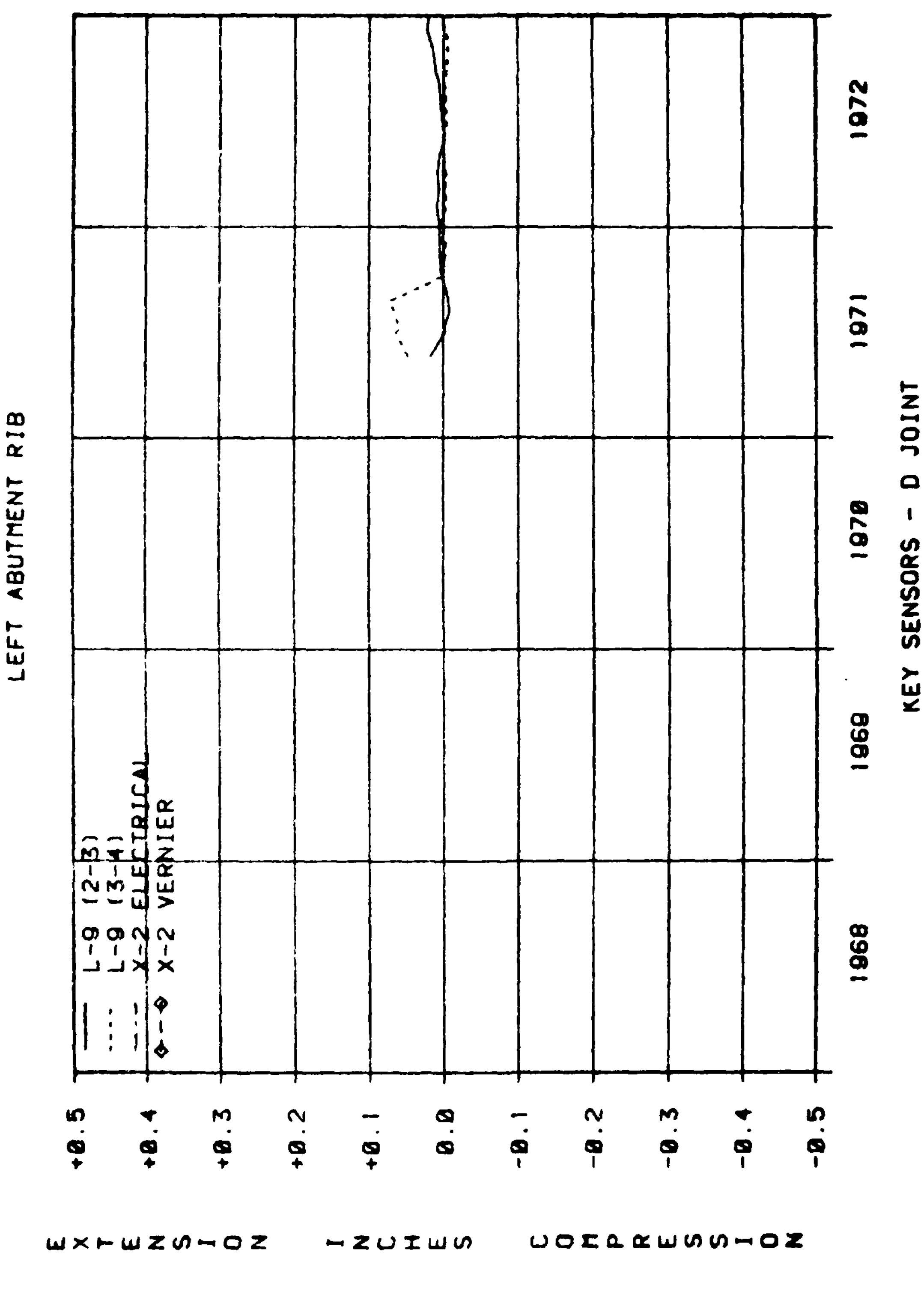

LEFT ABUTMENT RIB
L-9 (2-3)
L-9 (3-4)
X-2 ELECTRICAL
X-2 VERNIER
+0.5
+0.4
+0.3
+0.2
+0.1
0.0
-0.1
-0.2
-0.3
-0.4
-0.5
EXTENSION INCHES COMPRESSION
1968
1969
1970
1971
1972
KEY SENSORS - D JOINT

Fig. 4.8a

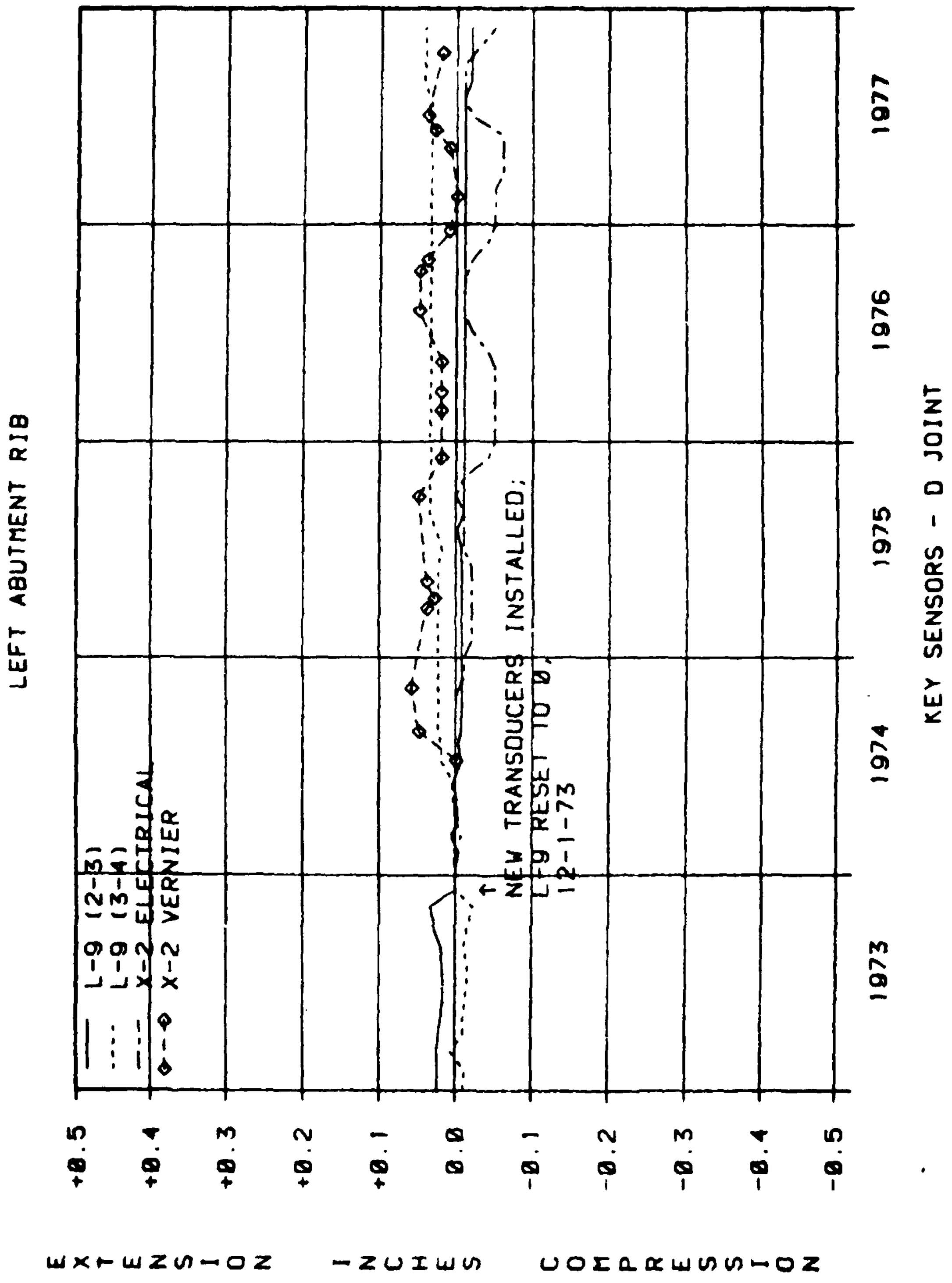

LEFT ABUTMENT RIB
KEY SENSORS - D JOINT
L-9 (2-3)
L-9 (3-4)
X-2 ELECTRICAL
X-2 VERNIER
NEW TRANSDUCERS INSTALLED;
L-9 RESET TO 0,
12-1-73
+0.5
+0.4
+0.3
+0.2
+0.1
0.0
-0.1
-0.2
-0.3
-0.4
-0.5
1973
1974
1975
1976
1977
EXTENSION
INCHES
COMPRESSION

Fig. 4.8b

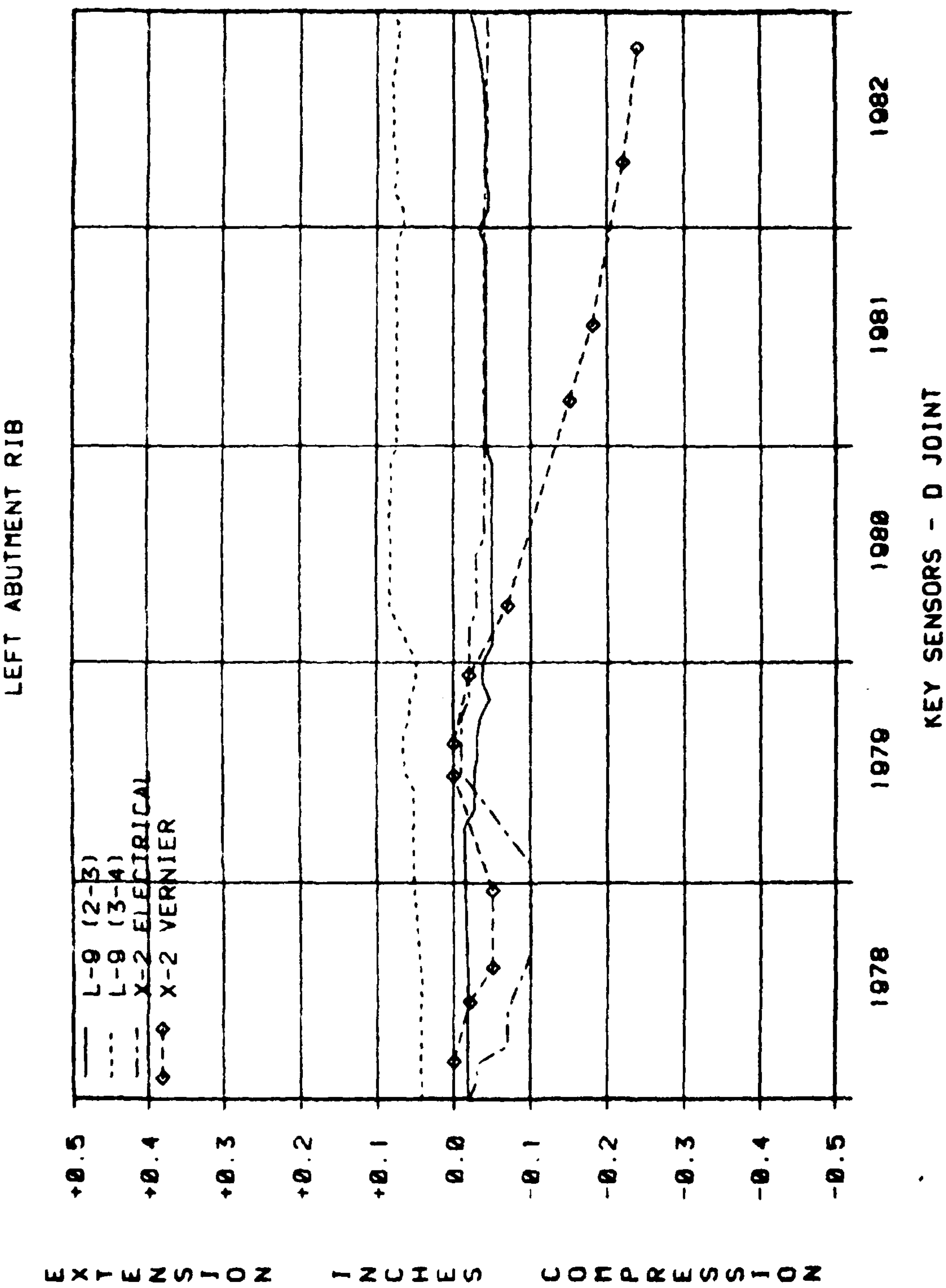
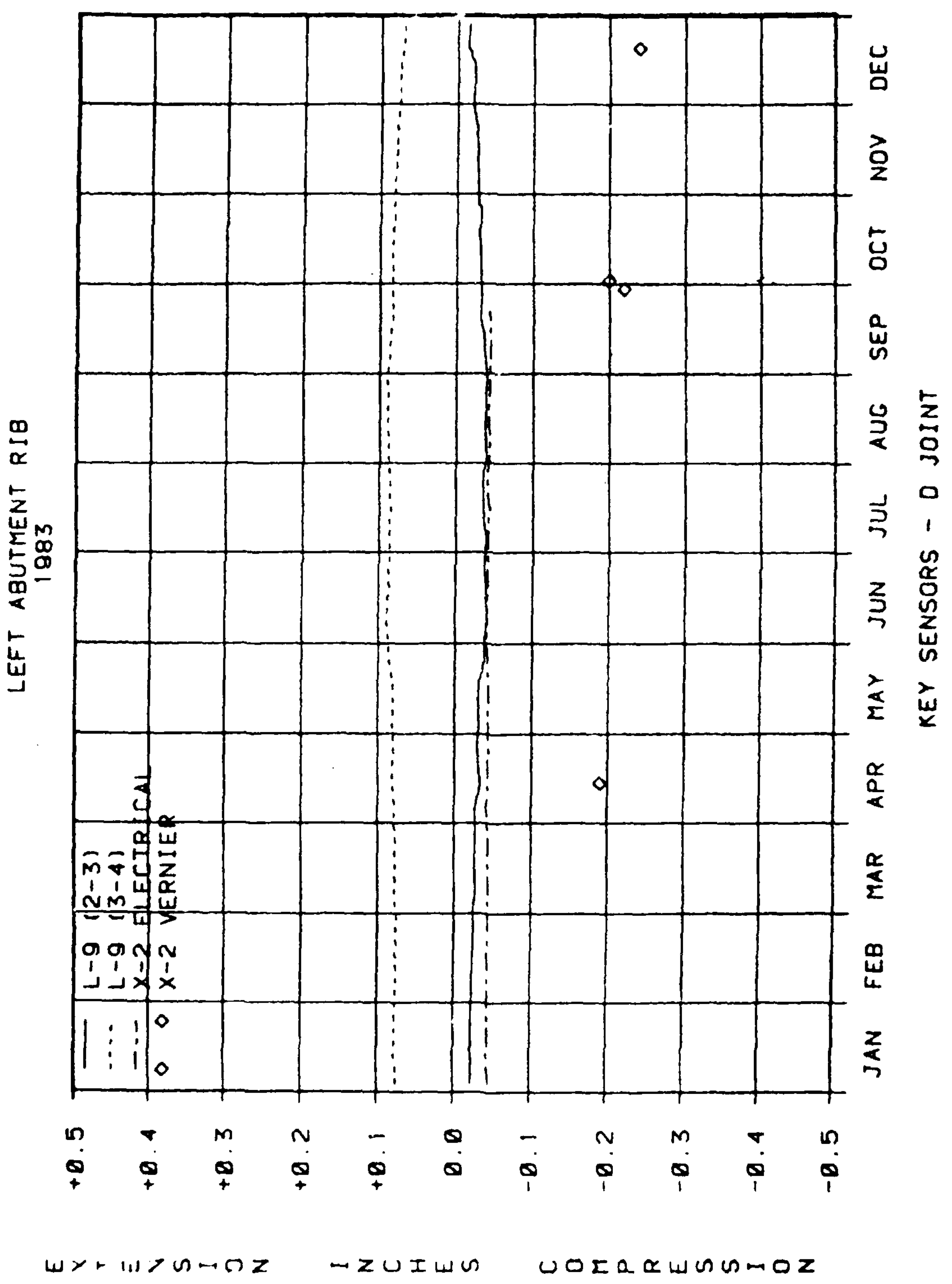
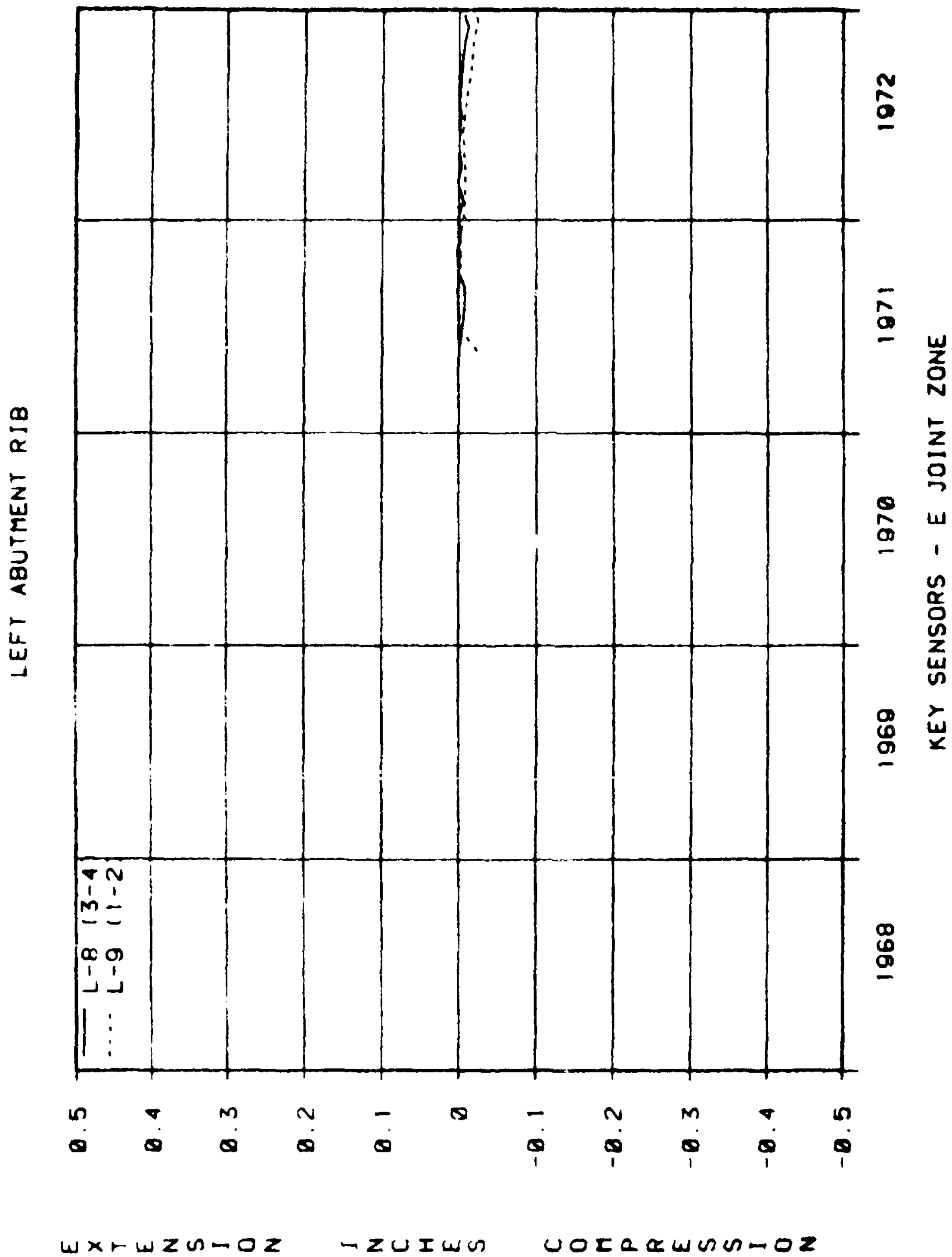

LEFT ABUTMENT RIB
L-9 (2-3)
L-9 (3-4)
X-2 ELECTRICAL
X-2 VERNIER
+0.5
+0.4
+0.3
+0.2
+0.1
0.0
-0.1
-0.2
-0.3
-0.4
-0.5
EXTENSION INCHES COMPRESSION
1978
1979
1980
1981
1982
KEY SENSORS - D JOINT

Fig. 4.8c



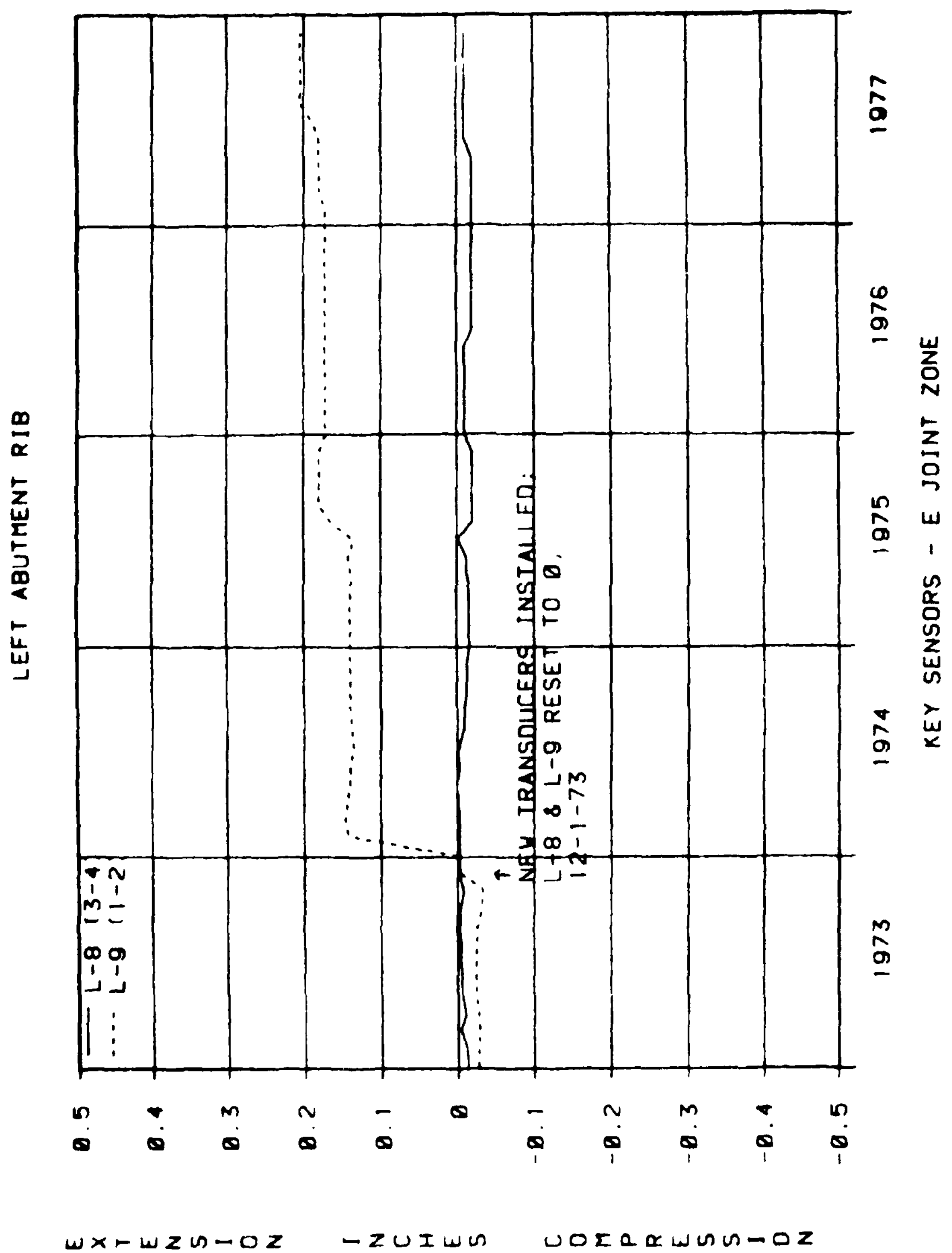
LEFT ABUTMENT RIB
1983
L-9 (2-3)
L-9 (3-4)
X-2 ELECTRICAL
X-2 VERNIER
JAN FEB MAR APR MAY JUN JUL AUG SEP OCT NOV DEC
KEY SENSORS - D JOINT
+0.5 +0.4 +0.3 +0.2 +0.1 0.0 -0.1 -0.2 -0.3 -0.4 -0.5
EXTENSION INCHES COMPRESSION

Fig 4.8d



LEFT ABUTMENT RIB
KEY SENSORS - E JOINT ZONE
L-8 (3-4
L-9 (1-2
1968
1969
1970
1971
1972
0.5
0.4
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
-0.4
-0.5
EXTENSION
INCHES
COMPRESSION

Fig. 4.9a



LEFT ABUTMENT RIB
L-8 (3-4
L-9 (1-2
NEW TRANSDUCERS INSTALLED;
L-8 & L-9 RESET TO Ø,
12-1-73
Ø.5
Ø.4
Ø.3
Ø.2
Ø.1
Ø
-Ø.1
-Ø.2
-Ø.3
-Ø.4
-Ø.5
EXTENSION INCHES COMPRESSION
1973
1974
1975
1976
1977
KEY SENSORS - E JOINT ZONE

Fig. 4.9b

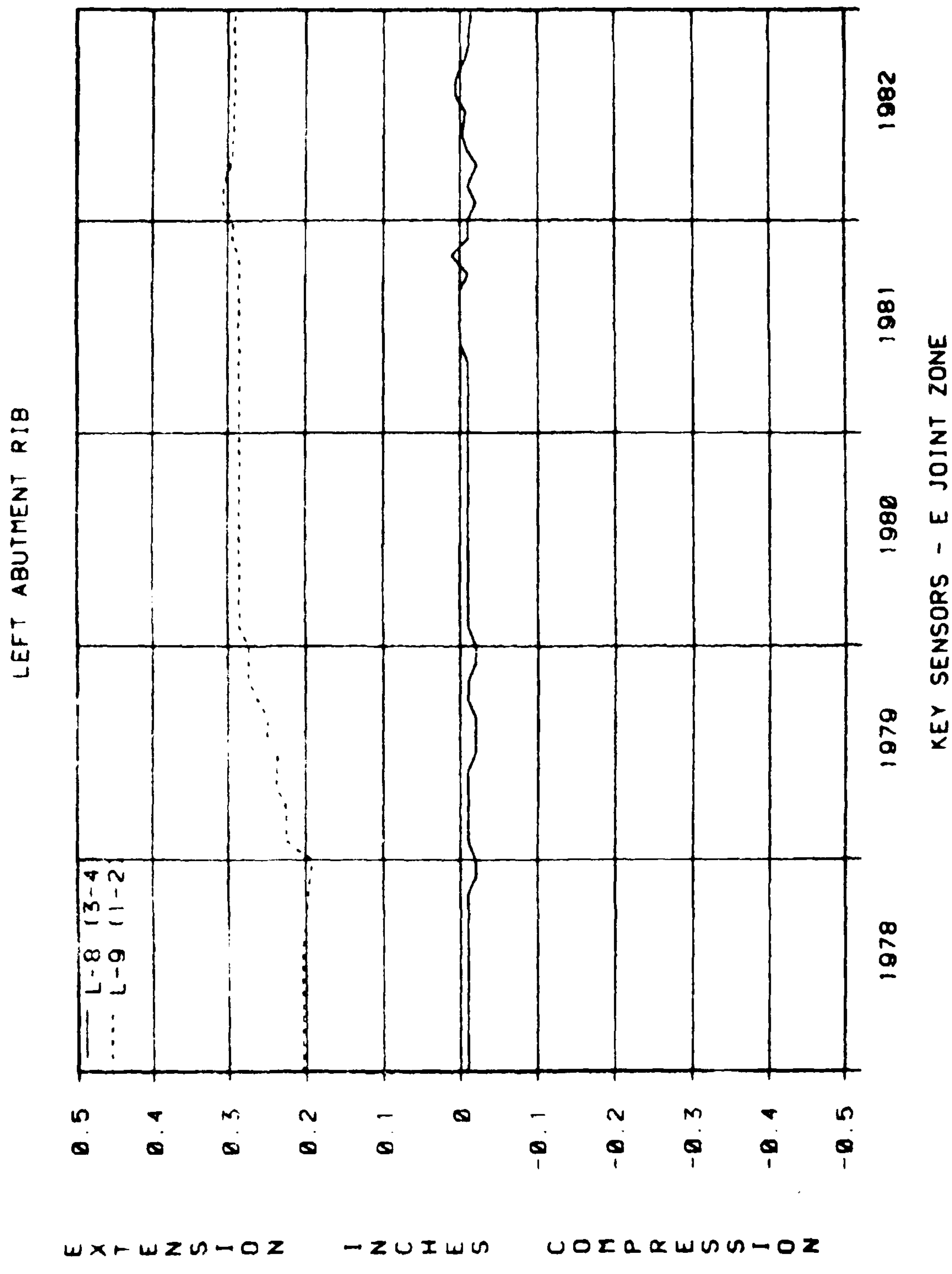

LEFT ABUTMENT RIB
L-8 (3-4
L-9 (1-2
0.5
0.4
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
-0.4
-0.5
EXTENSION INCHES COMPRESSION
1978
1979
1980
1981
1982
KEY SENSORS - E JOINT ZONE

Fig. 4.9c

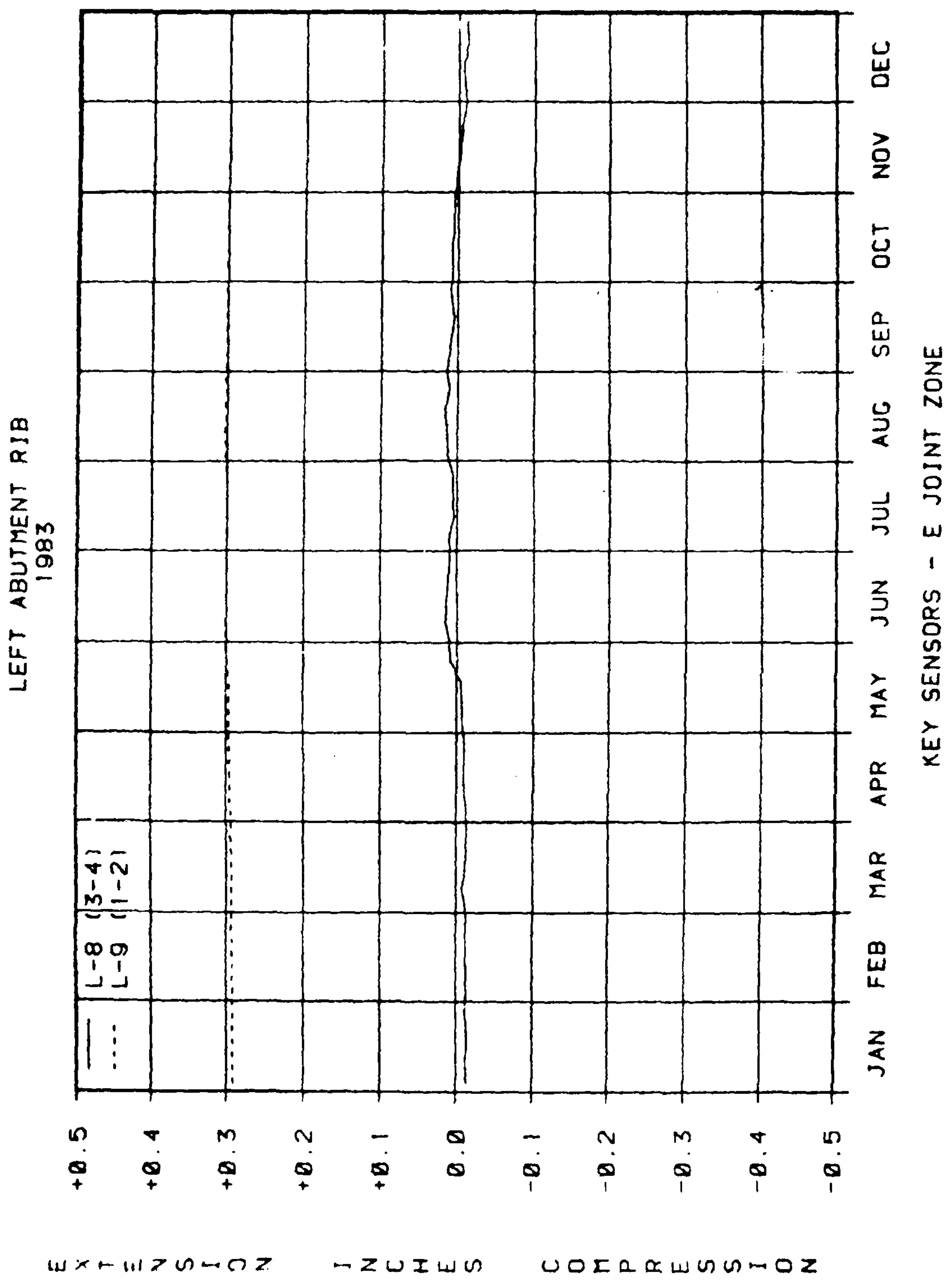

LEFT ABUTMENT RIB
1983
L-8 (3-4)
L-9 (1-2)
JAN FEB MAR APR MAY JUN JUL AUG SEP OCT NOV DEC
+0.5 +0.4 +0.3 +0.2 +0.1 0.0 -0.1 -0.2 -0.3 -0.4 -0.5
EXTENSION INCHES COMPRESSION
KEY SENSORS - E JOINT ZONE

Fig 4.9d

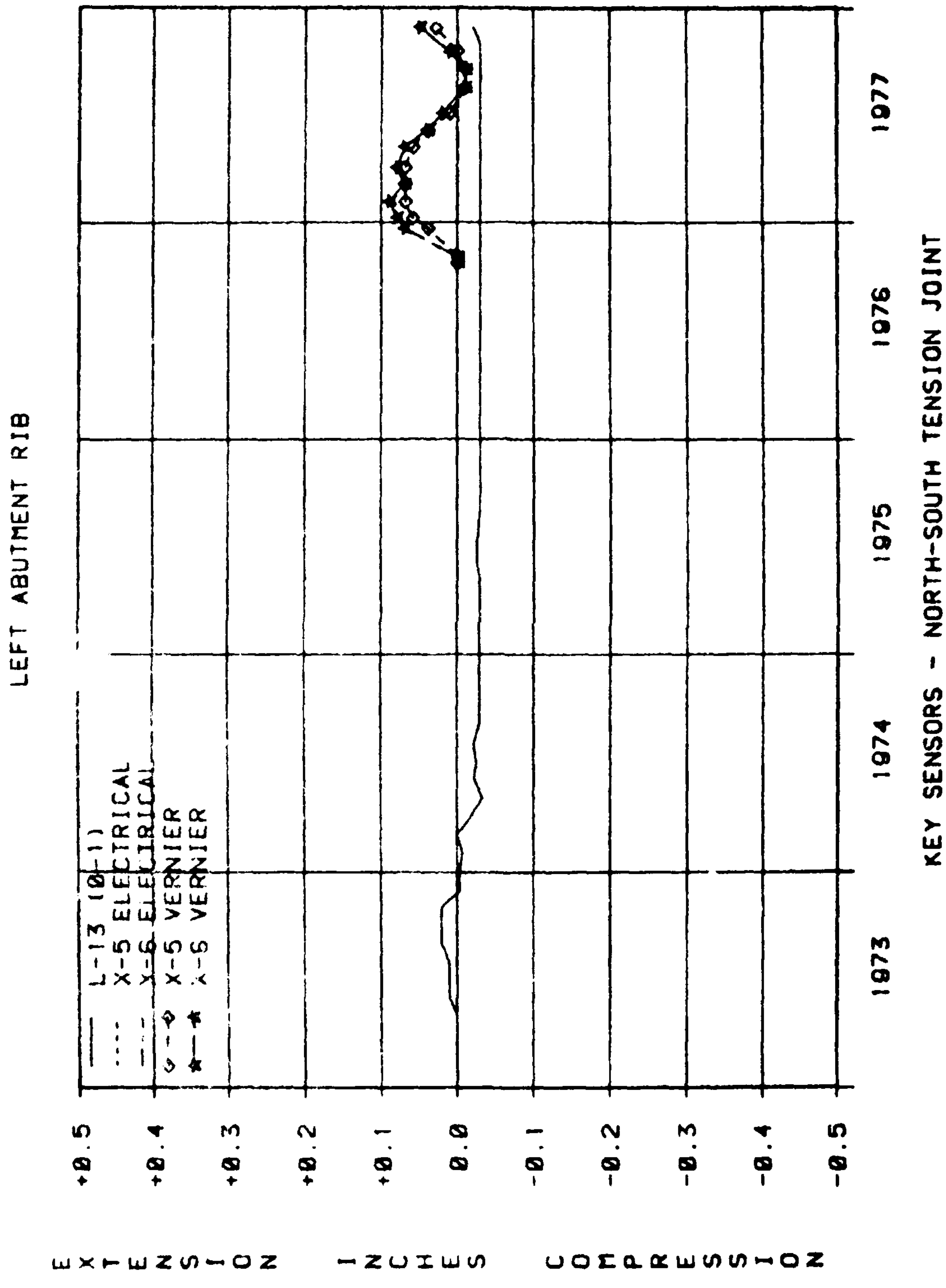
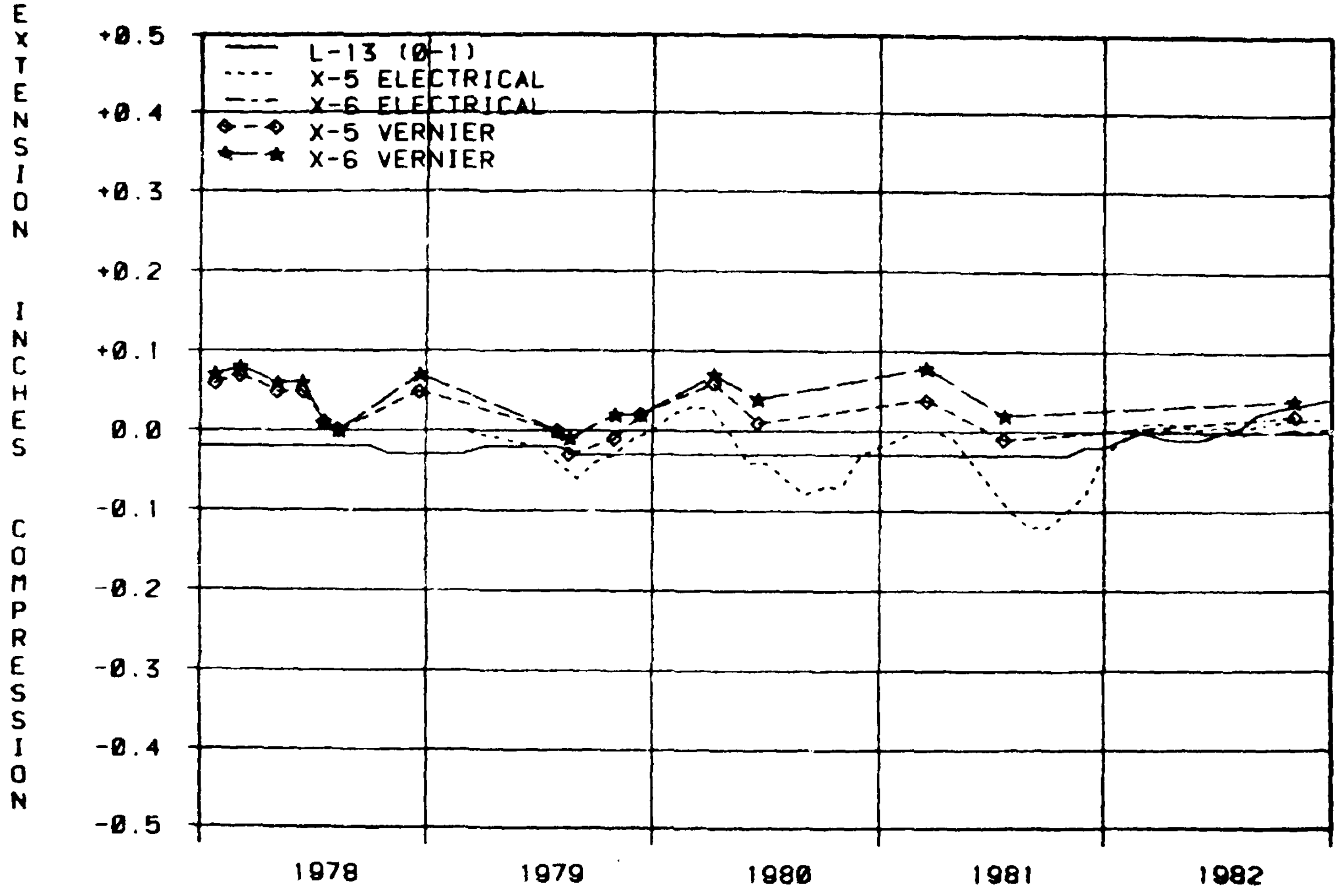

LEFT ABUTMENT RIB
L-13 (0-1)
X-5 ELECTRICAL
X-6 ELECTRICAL
X-5 VERNIER
X-6 VERNIER
+0.5
+0.4
+0.3
+0.2
+0.1
0.0
-0.1
-0.2
-0.3
-0.4
-0.5
EXTENSION INCHES COMPRESSION
1973
1974
1975
1976
1977
KEY SENSORS - NORTH-SOUTH TENSION JOINT

Fig. 4.10a

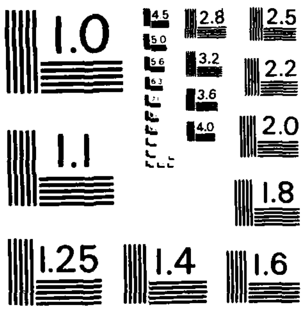
LEFT ABUTMENT RIB



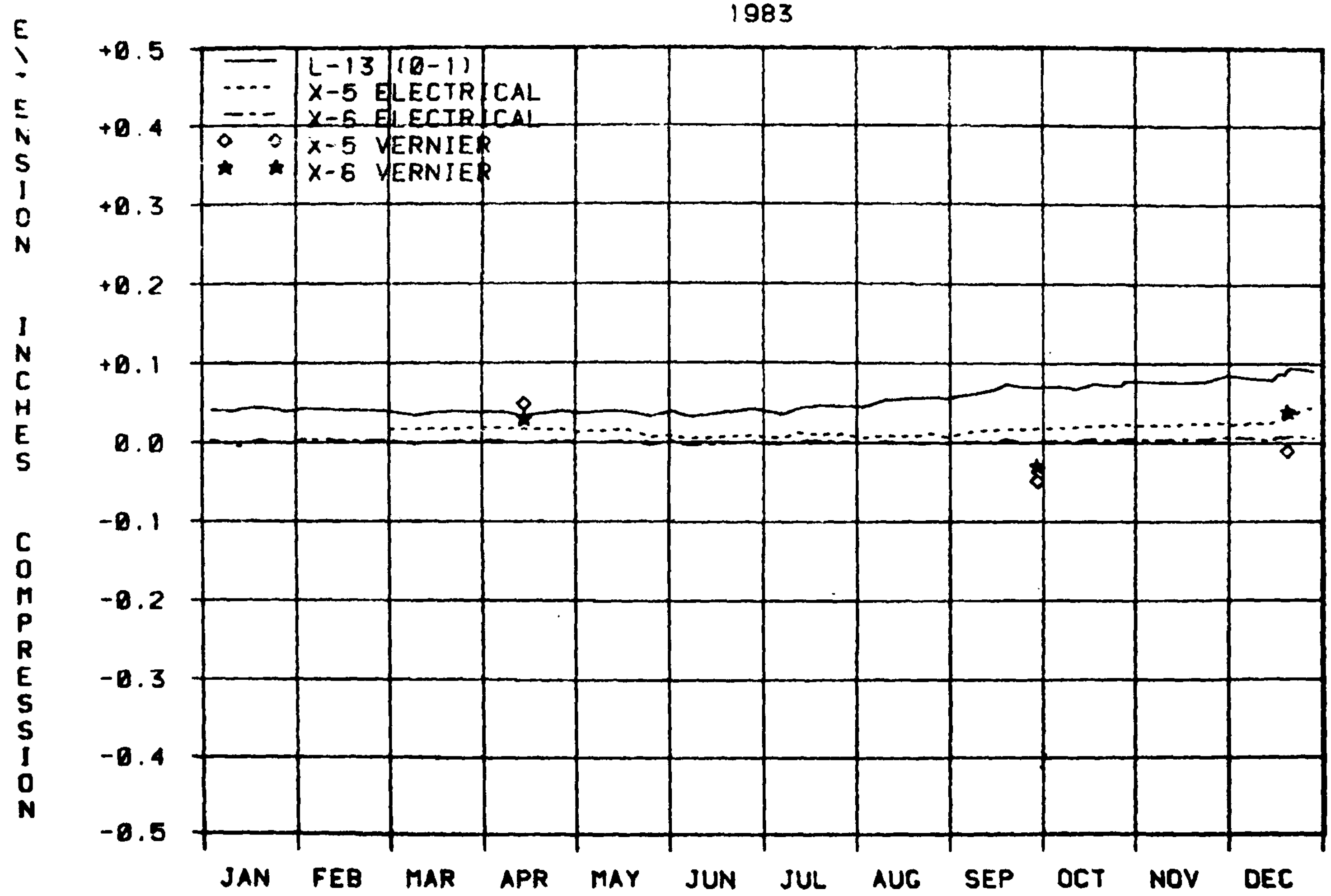
KEY SENSORS - NORTH-SOUTH TENSION JOINT

AD-A142 021 LIBBY DAM AND LAKE KOOCANUSA PROJECT MONTANA LEFT BANK SLOPE(U) CORPS OF ENGINEERS SEATTLE WA SEATTLE DISTRICT APR 84 2/6

UNCLASSIFIED F/G 13/2 NL


1.0
1.1
1.25
1.4
1.6
1.8
2.0
2.2
2.5
2.8
3.2
3.6
4.0
4.5
5.0
5.6
6.3

LEFT ABUTMENT RIB
1983



KEY SENSORS - NORTH-SOUTH TENSION JOINT

Fig 4.10c

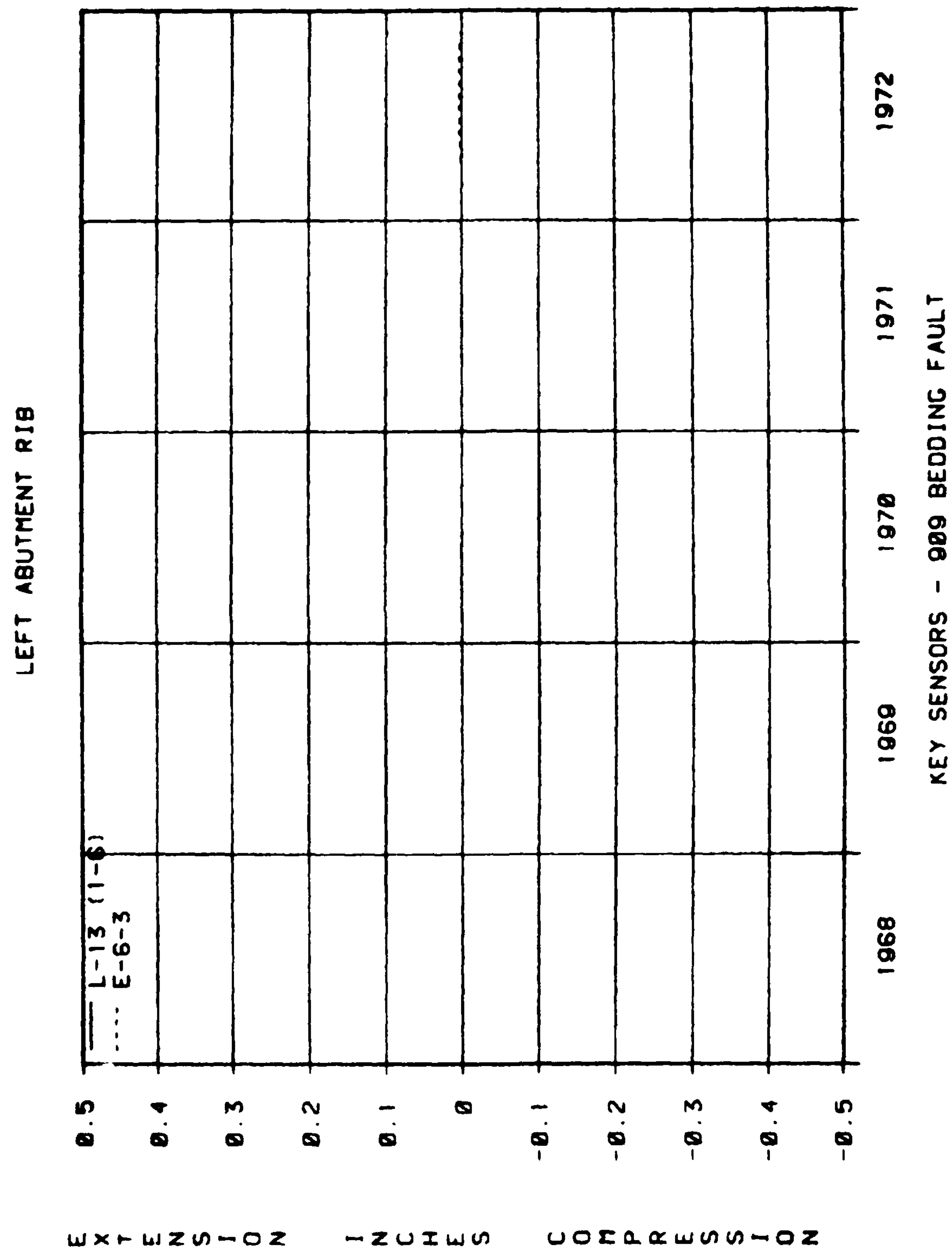
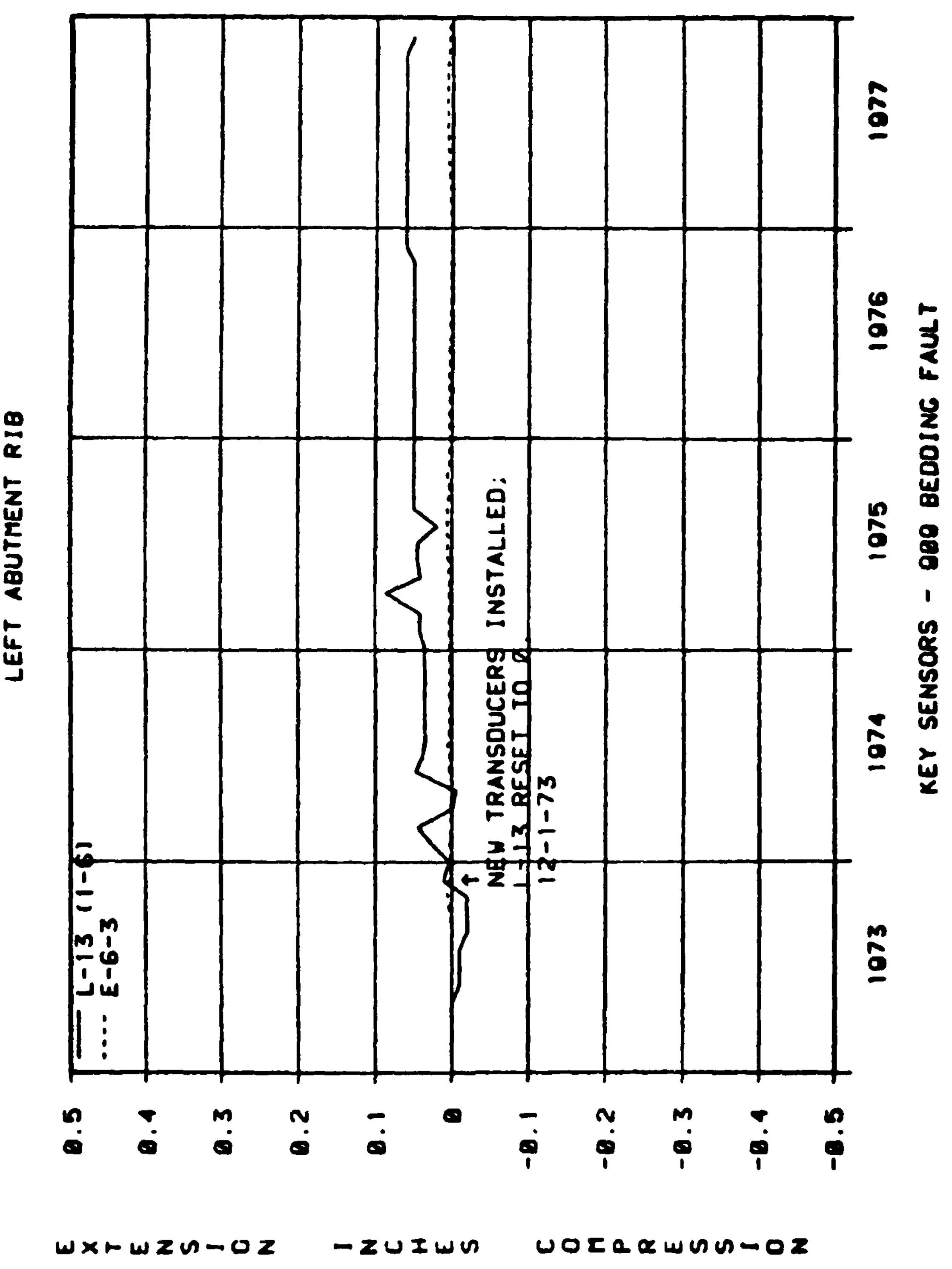

LEFT ABUTMENT RIB
L-13 (1-6)
E-6-3
0.5
0.4
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
-0.4
-0.5
EXTENSION INCHES COMPRESSION
1968
1969
1970
1971
1972
KEY SENSORS - 909 BEDDING FAULT

Fig. 4.11a



LEFT ABUTMENT RIB
L-13 (1-6)
E-6-3
NEW TRANSDUCERS INSTALLED;
L-13 RESET TO 0
12-1-73
0.5
0.4
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
-0.4
-0.5
EXTENSION
INCHES
COMPRESSION
1973
1974
1975
1976
1977
KEY SENSORS - 900 BEDDING FAULT

Fig. 4.11b

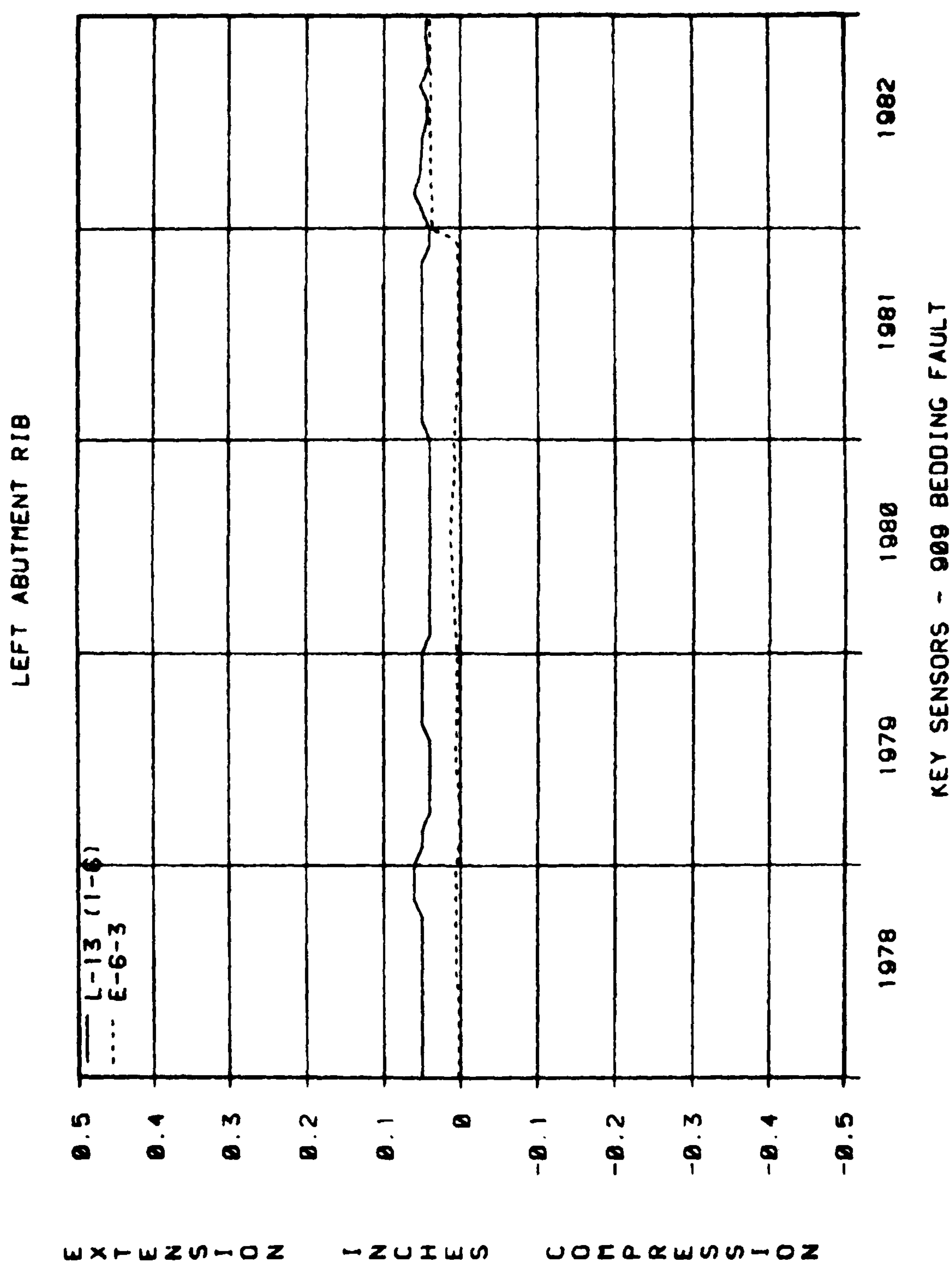

LEFT ABUTMENT RIB
L-13 (1-6)
E-6-3
0.5
0.4
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
-0.4
-0.5
EXTENSION INCHES COMPRESSION
1978
1979
1980
1981
1982
KEY SENSORS - 909 BEDDING FAULT

Fig. 4.11c

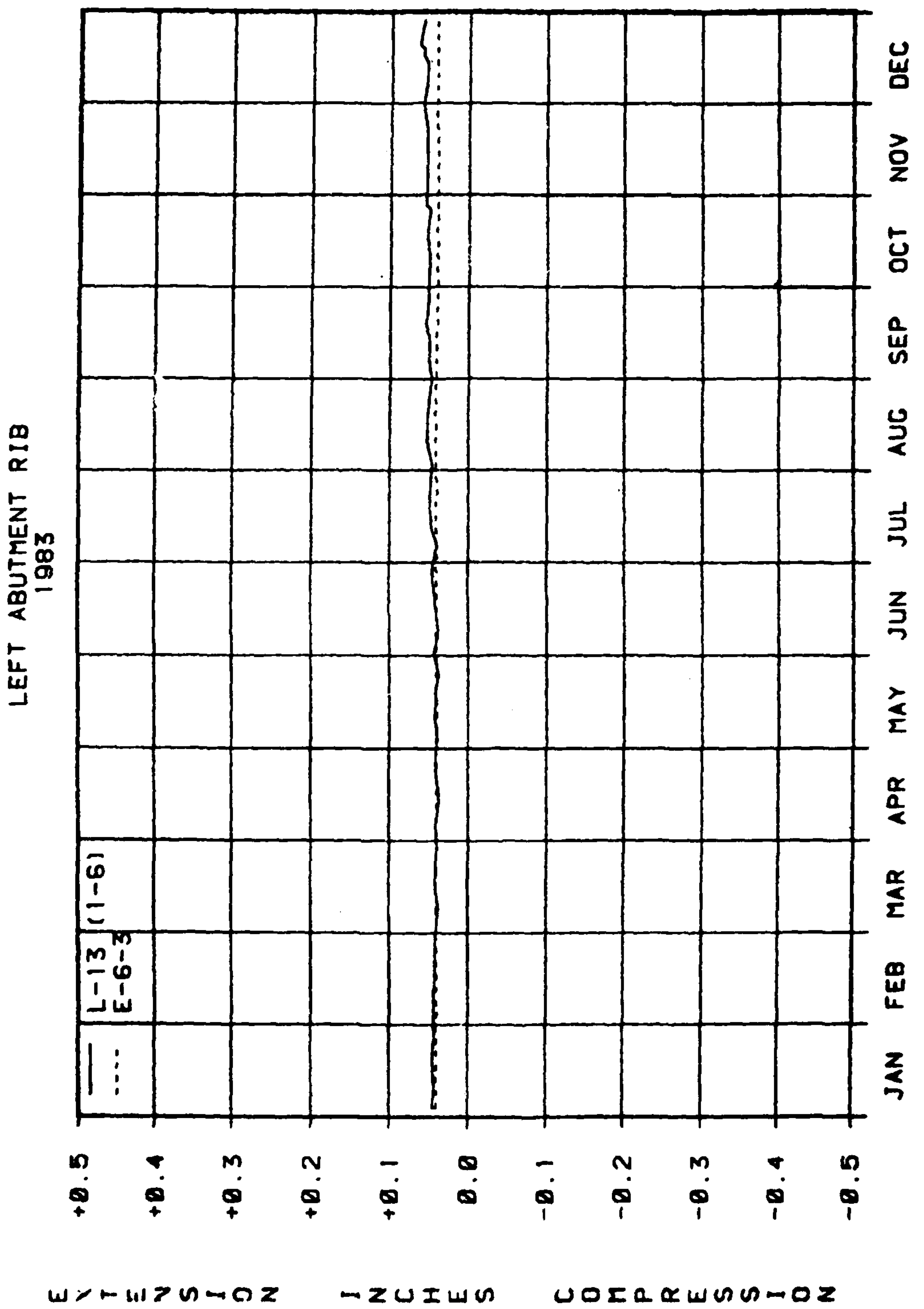

LEFT ABUTMENT RIB
1983
KEY SENSORS - 909 BEDDING FAULT
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC
L-13 (1-6)
E-6-3
+0.5
+0.4
+0.3
+0.2
+0.1
0.0
-0.1
-0.2
-0.3
-0.4
-0.5
EXTENSION
INCHES
COMPRESSION

Fig 4.11d

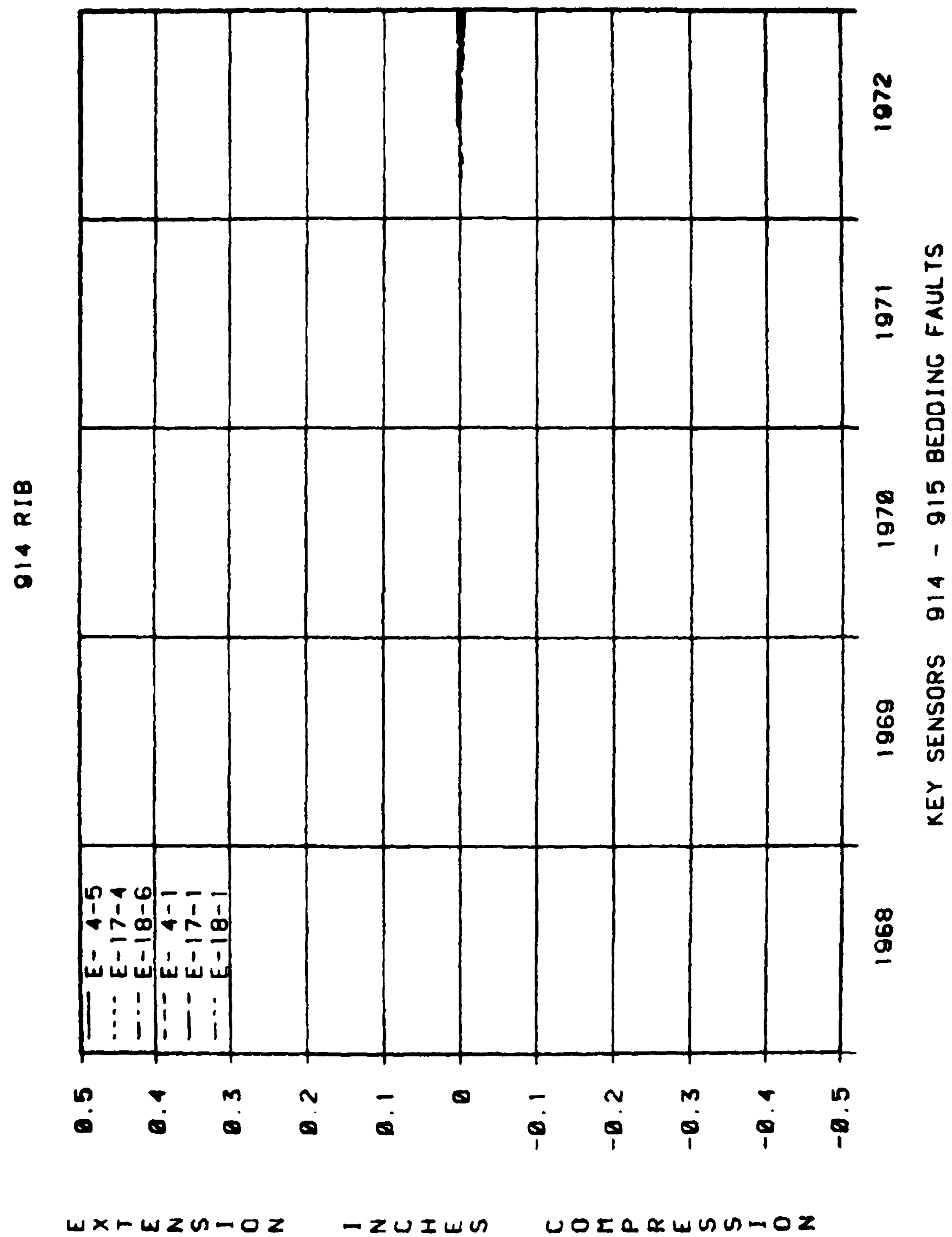

914 RIB
KEY SENSORS 914 - 915 BEDDING FAULTS
E- 4-5
E-17-4
E-18-6
E- 4-1
E-17-1
E-18-1
0.5
0.4
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
-0.4
-0.5
1968
1969
1970
1971
1972
EXTENSION INCHES COMPRESSION

Fig. 4.12a

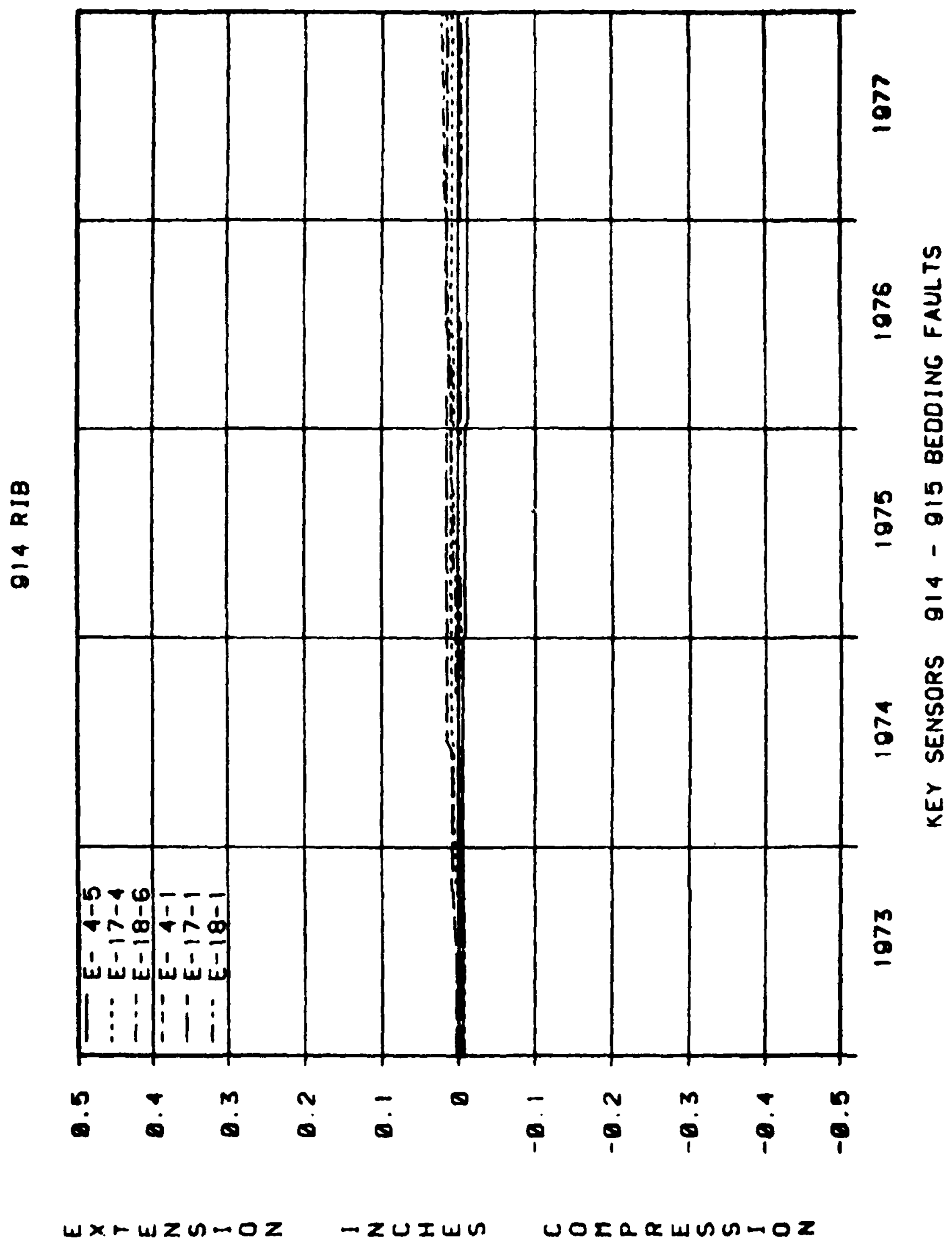

914 RIB
E- 4-5
E-17-4
E-18-6
E- 4-1
E-17-1
E-18-1
0.5
0.4
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
-0.4
-0.5
EXTENSION INCHES COMPRESSION
1973
1974
1975
1976
1977
KEY SENSORS 914 - 915 BEDDING FAULTS

Fig. 4.12b

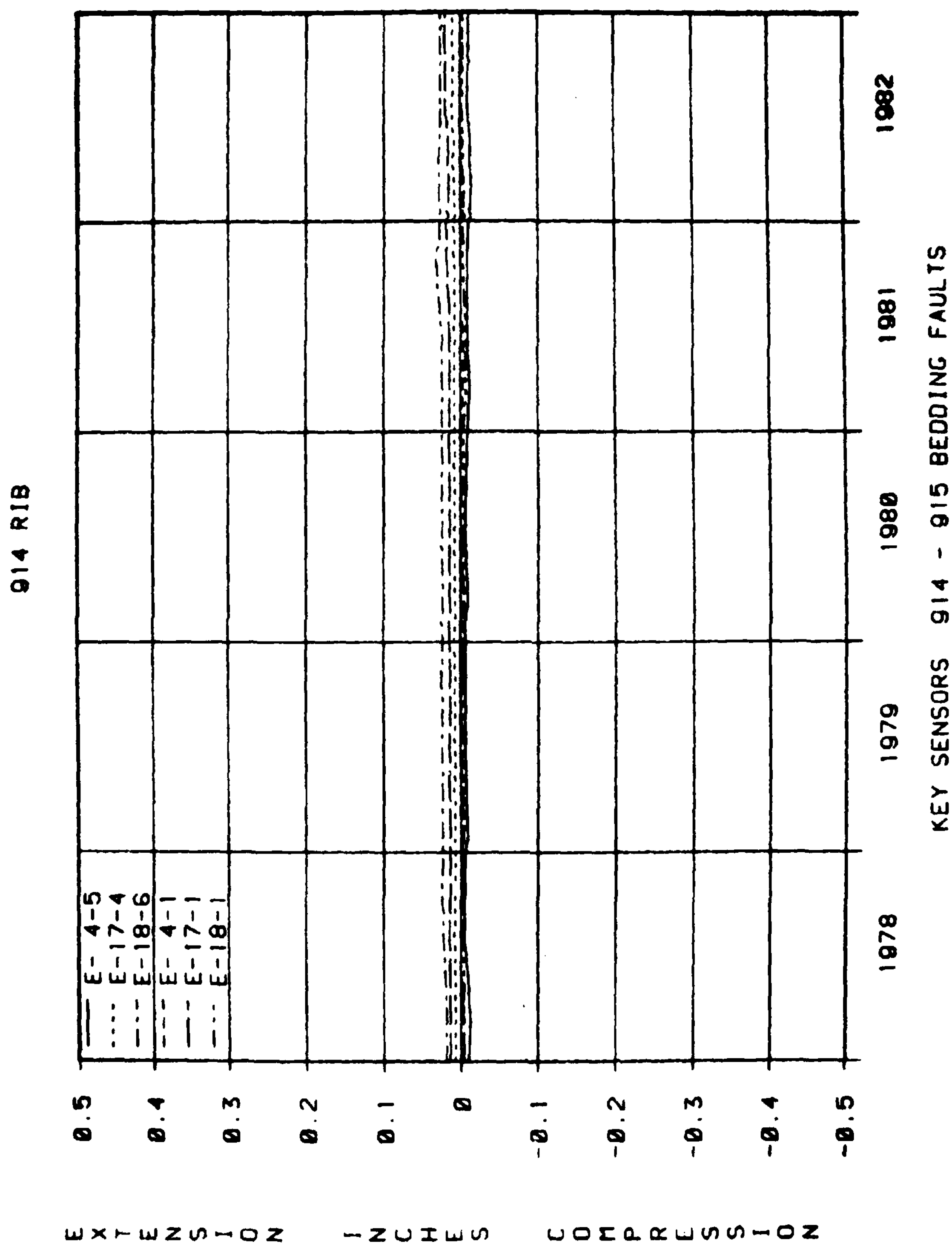

914 RIB
E- 4-5
E-17-4
E-18-6
E- 4-1
E-17-1
E-18-1
0.5
0.4
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
-0.4
-0.5
EXTENSION INCHES COMPRESSION
1978
1979
1980
1981
1982
KEY SENSORS 914 - 915 BEDDING FAULTS

Fig. 4.12c

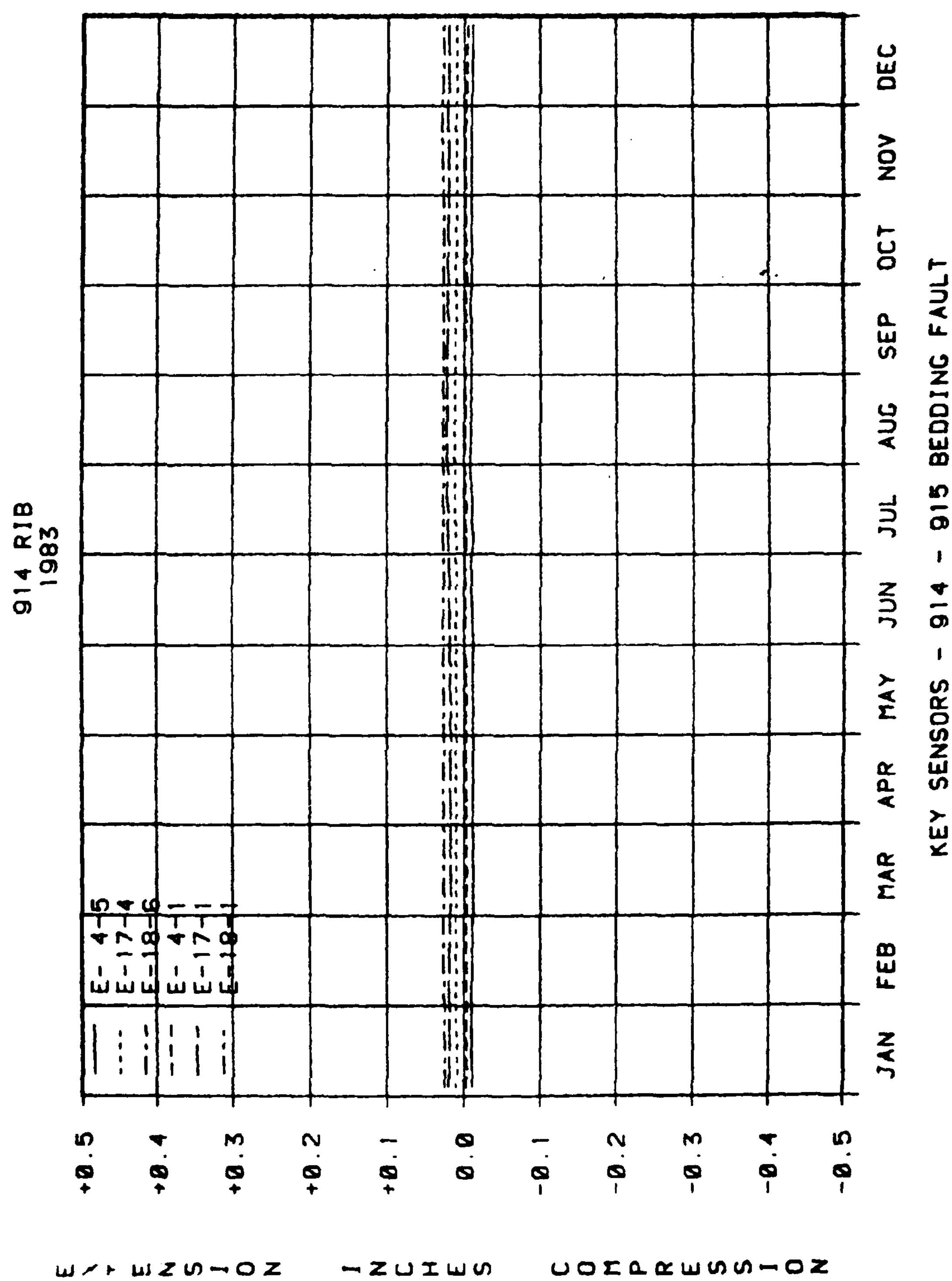

914 RIB
1983
E- 4-5
E-17-4
E-18-6
E- 4-1
E-17-1
E-18-1
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC
KEY SENSORS - 914 - 915 BEDDING FAULT
+0.5
+0.4
+0.3
+0.2
+0.1
0.0
-0.1
-0.2
-0.3
-0.4
-0.5
EXTENSION
INCHES
COMPRESSION

Fig 4.12d

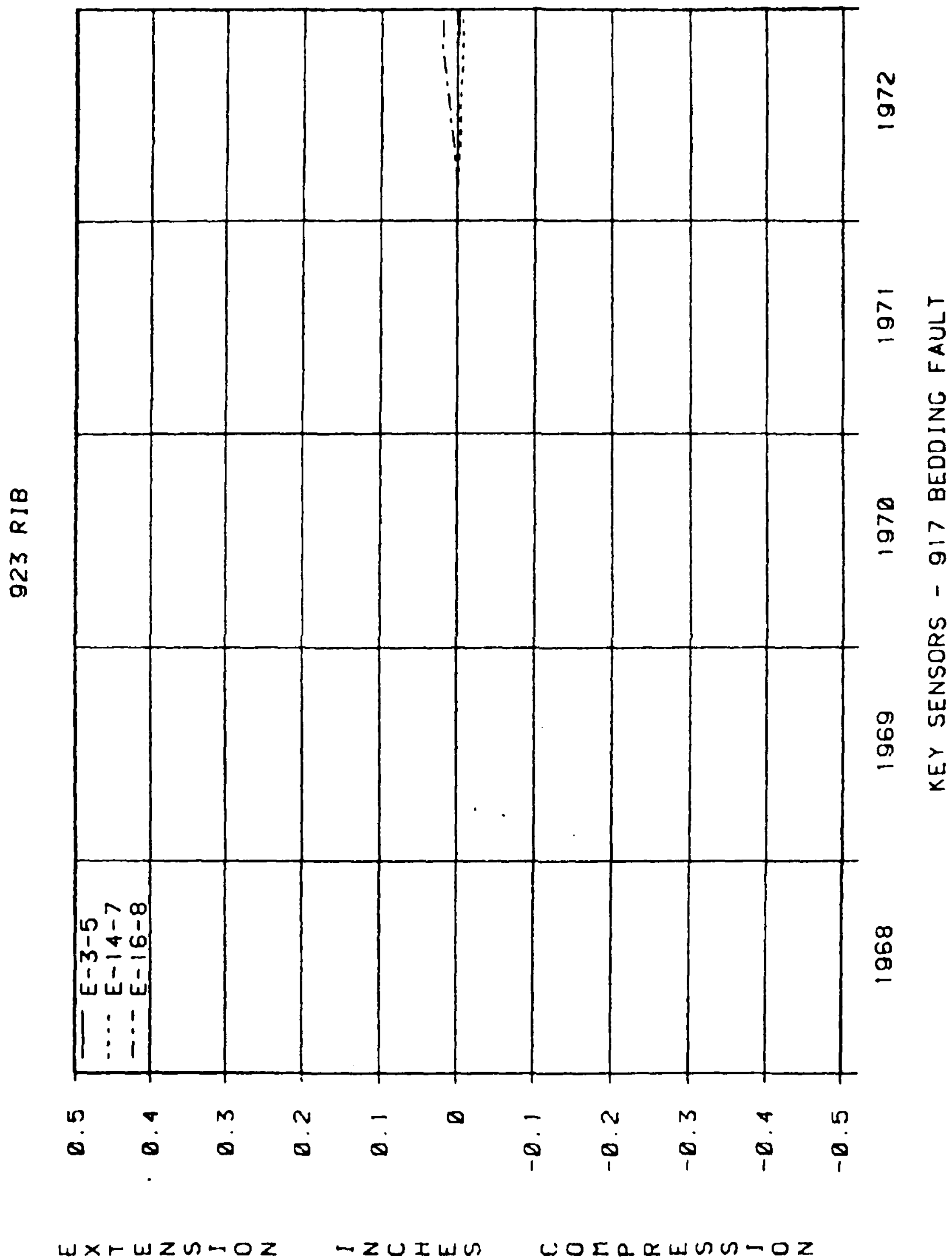

923 RIB
E-3-5
E-14-7
E-16-8
0.5
0.4
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
-0.4
-0.5
EXTENSION
INCHES
COMPRESSION
1968
1969
1970
1971
1972
KEY SENSORS - 917 BEDDING FAULT

Fig. 4.13a

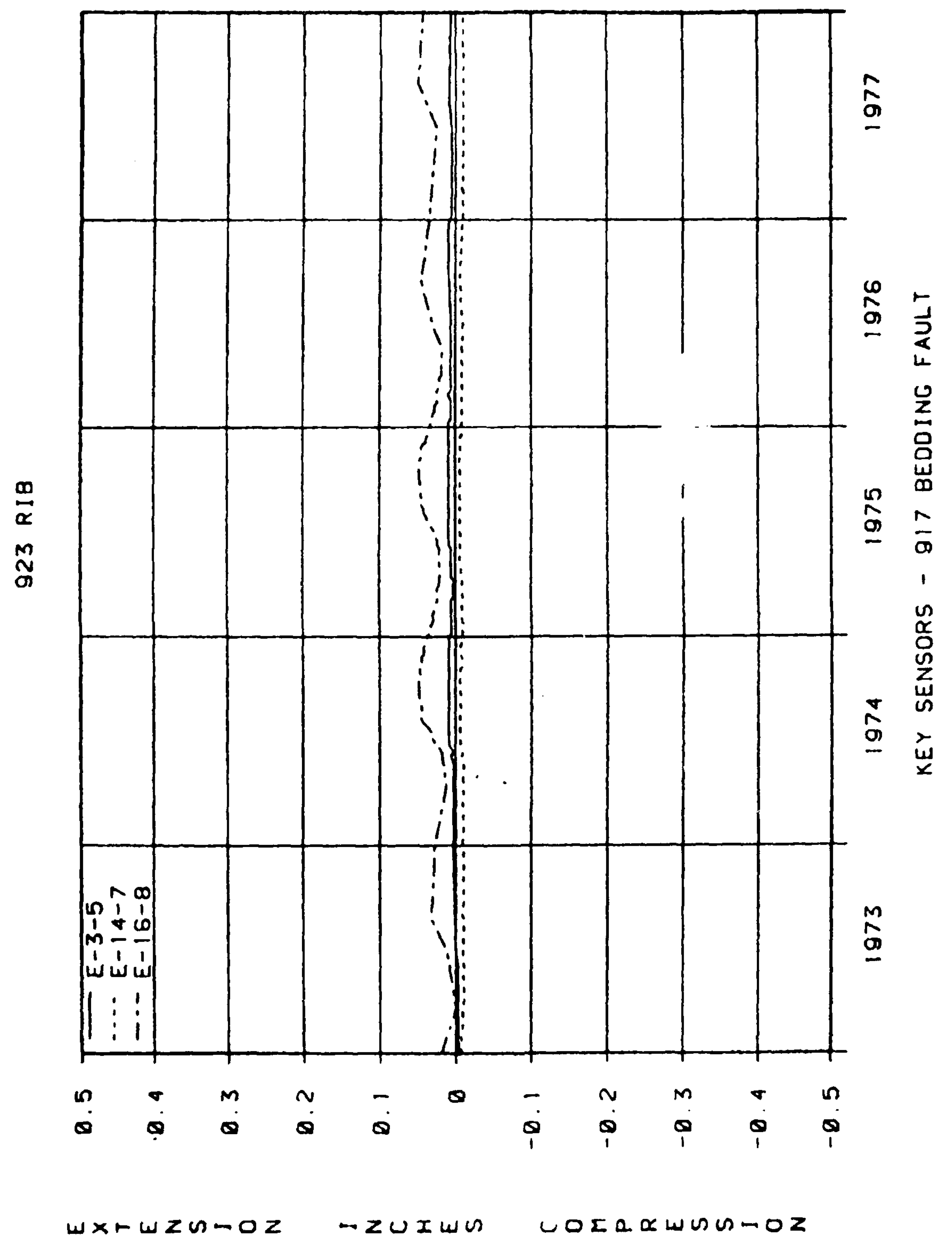
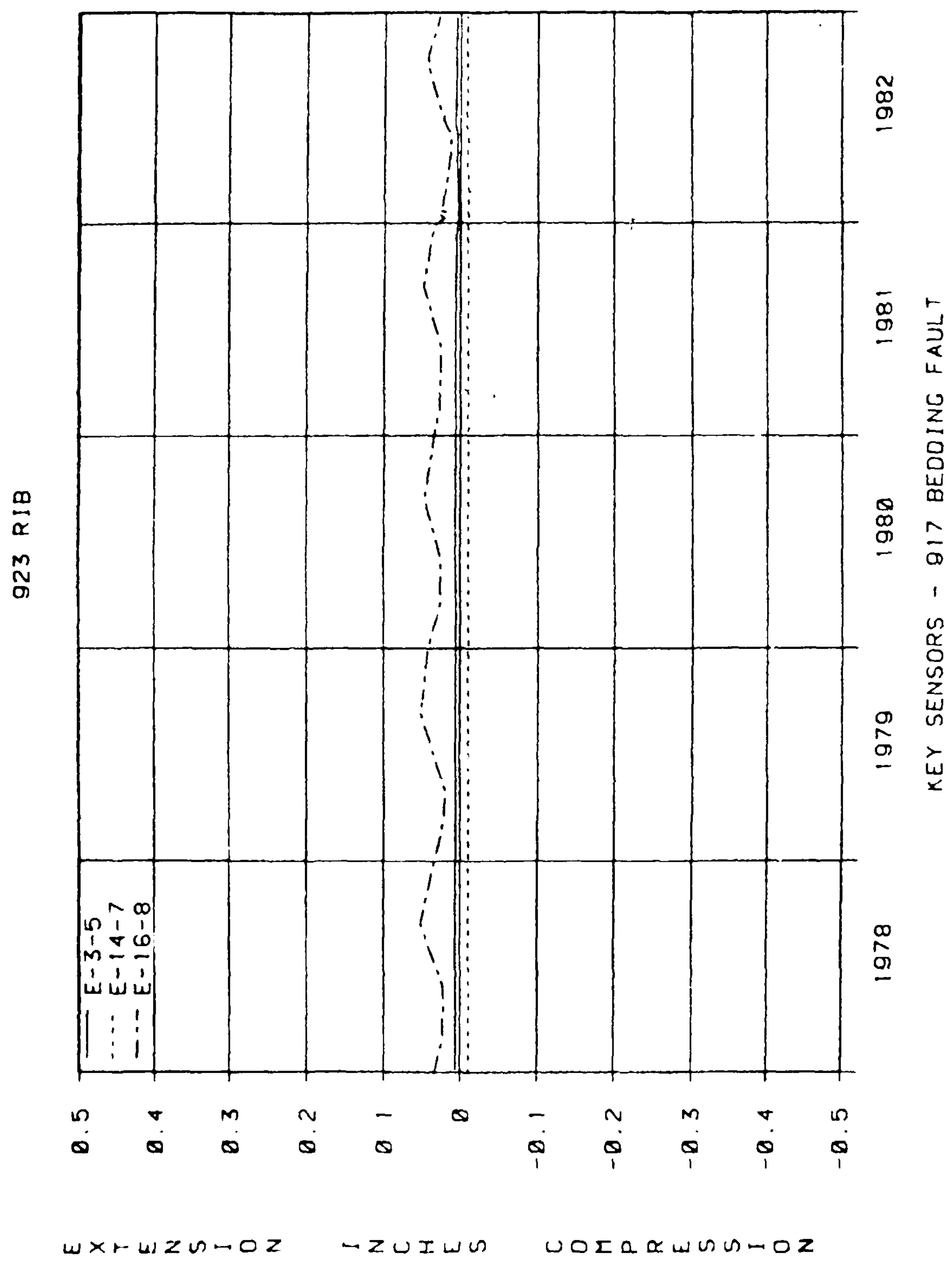

923 RIB
E-3-5
E-14-7
E-16-8
0.5
0.4
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
-0.4
-0.5
EXTENSION INCHES COMPRESSION
1973
1974
1975
1976
1977
KEY SENSORS - 917 BEDDING FAULT

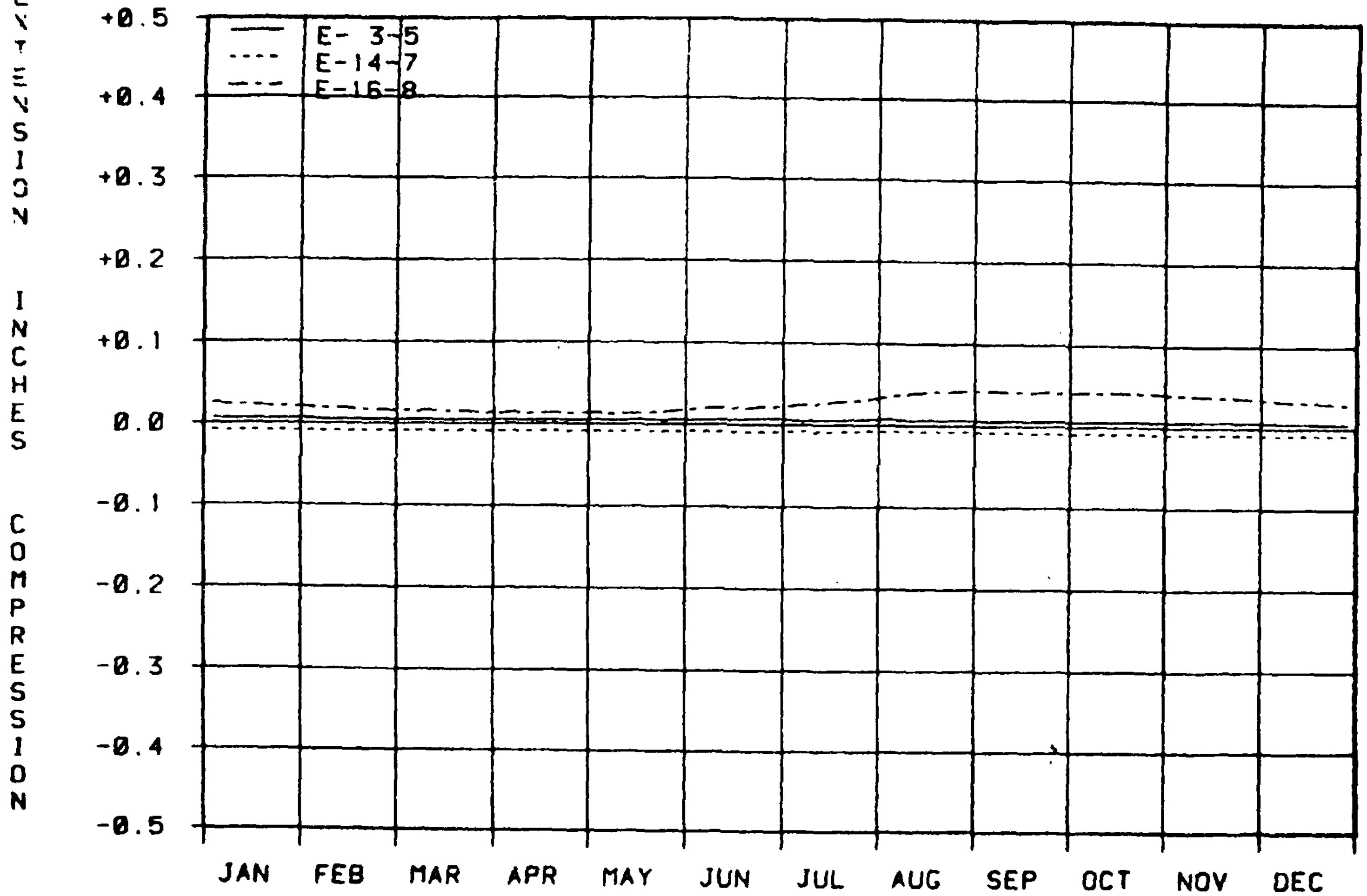
Fig. 4.13b



923 RIB
E-3-5
E-14-7
E-16-8
0.5
0.4
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
-0.4
-0.5
EXTENSION INCHES COMPRESSION
1978
1979
1980
1981
1982
KEY SENSORS - 917 BEDDING FAULT

Fig. 4.13c

923 RIB
1983



KEY SENSORS - 917 BEDDING FAULT

Fig 4.13d

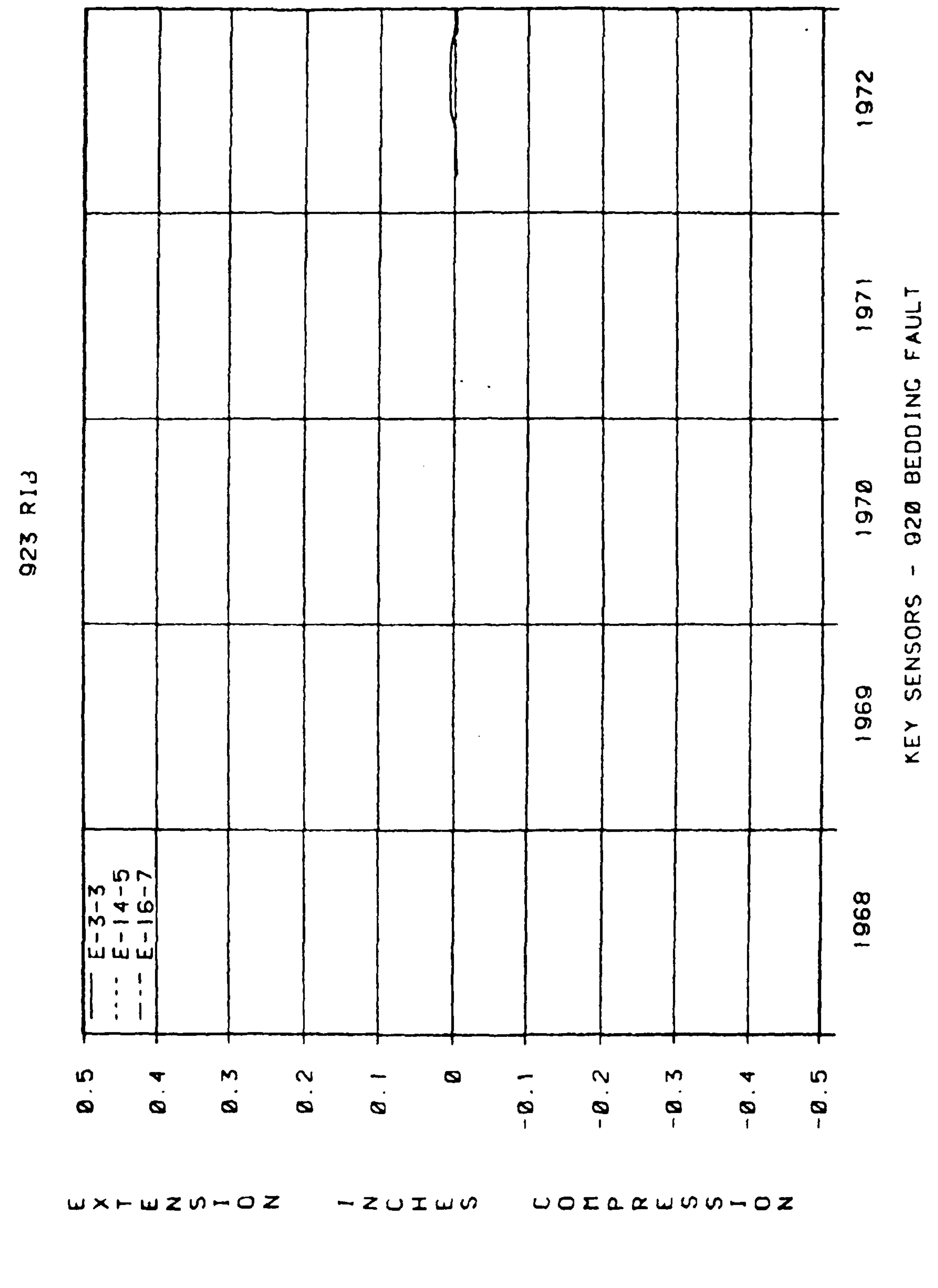

923 RIB
KEY SENSORS - 920 BEDDING FAULT
E-3-3
E-14-5
E-16-7
0.5
0.4
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
-0.4
-0.5
EXTENSION INCHES COMPRESSION
1968
1969
1970
1971
1972

Fig. 4.14a

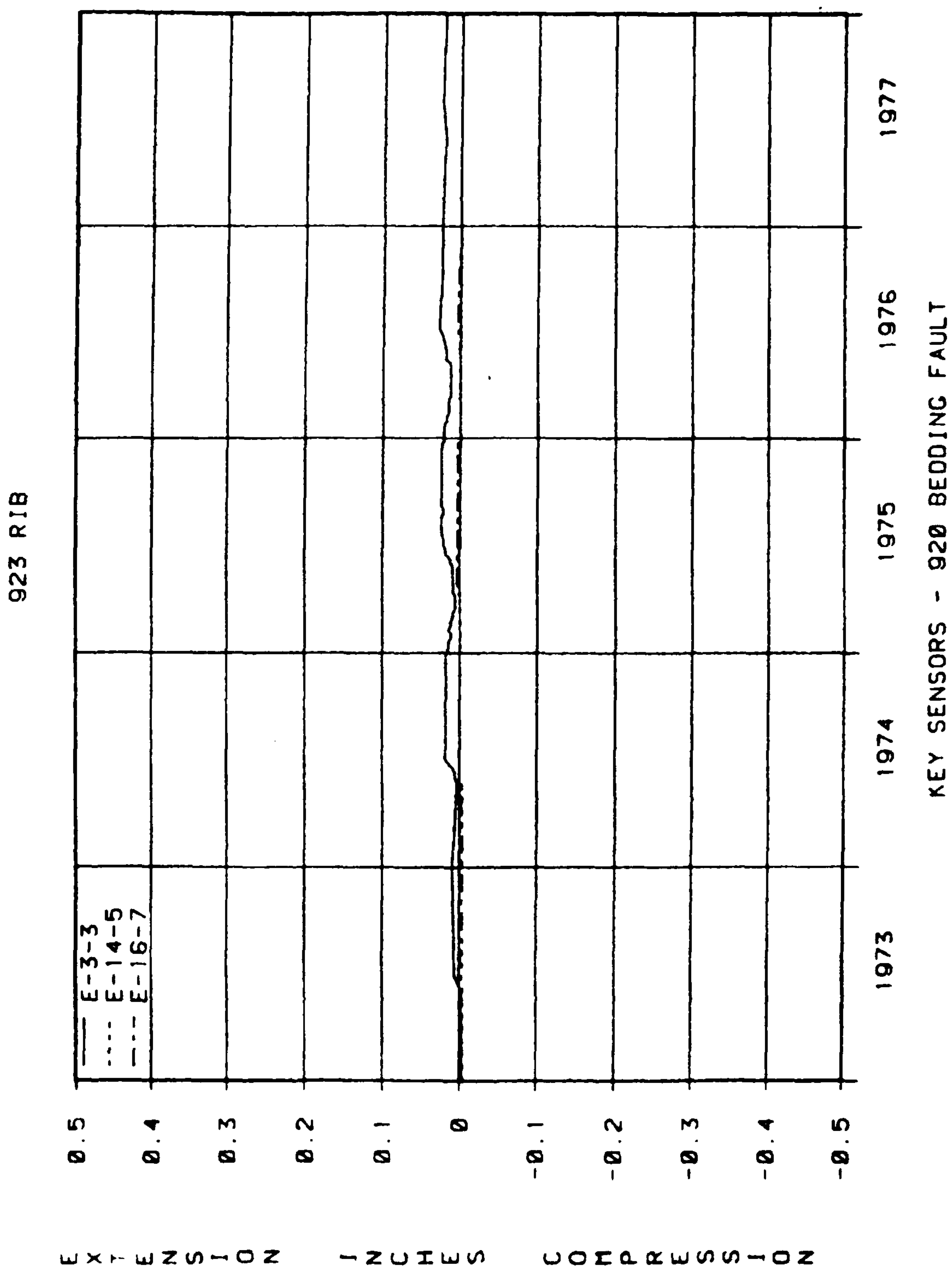

923 RIB
E-3-3
E-14-5
E-16-7
0.5
0.4
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
-0.4
-0.5
1973
1974
1975
1976
1977
KEY SENSORS - 920 BEDDING FAULT
EXTENSION
INCHES
COMPRESSION

Fig. 4.14b

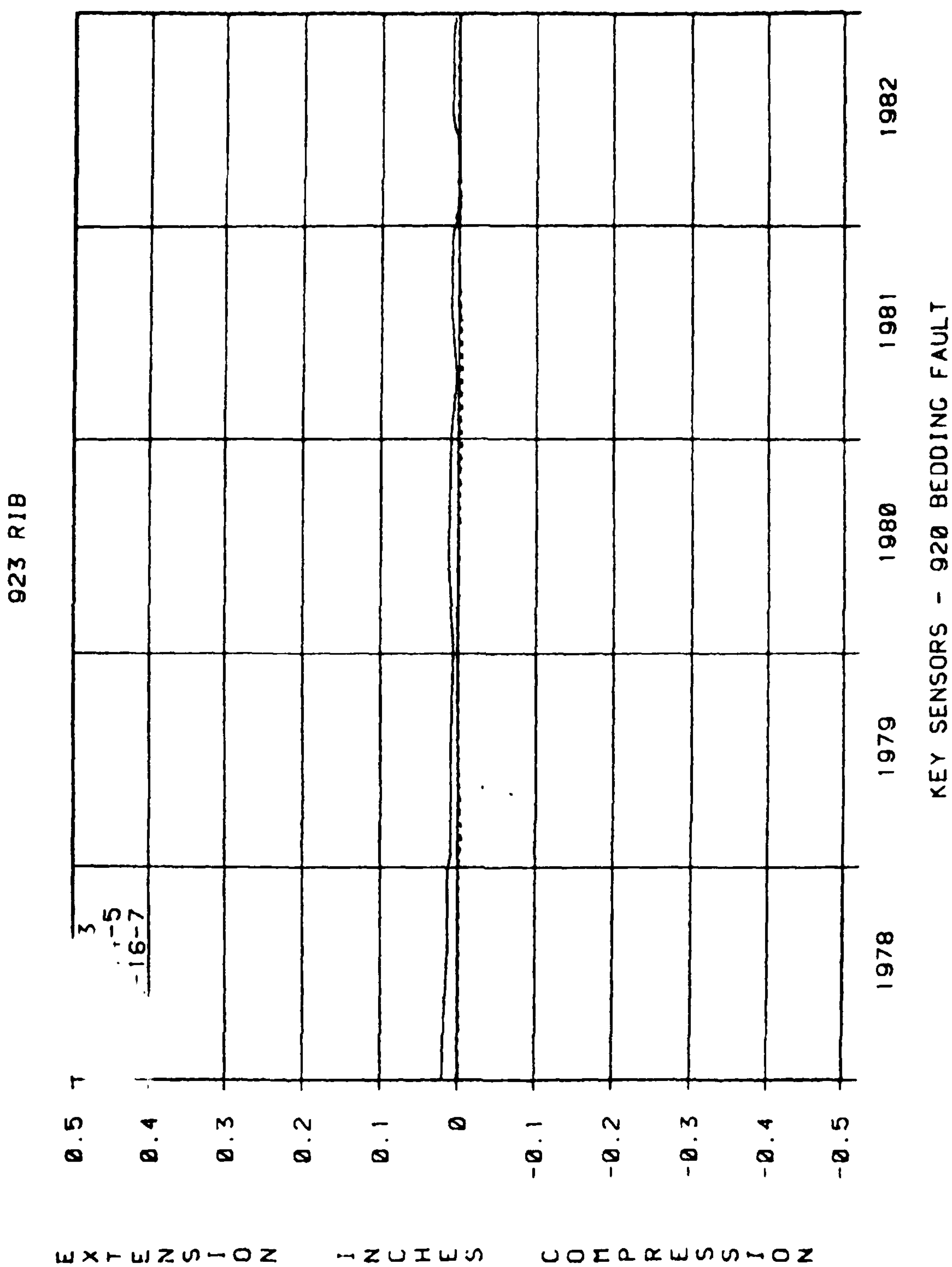

923 RIB
KEY SENSORS - 920 BEDDING FAULT
1978
1979
1980
1981
1982
0.5
0.4
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
-0.4
-0.5
EXTENSION
INCHES
COMPRESSION
3
5
16-7

Fig. 4.14c

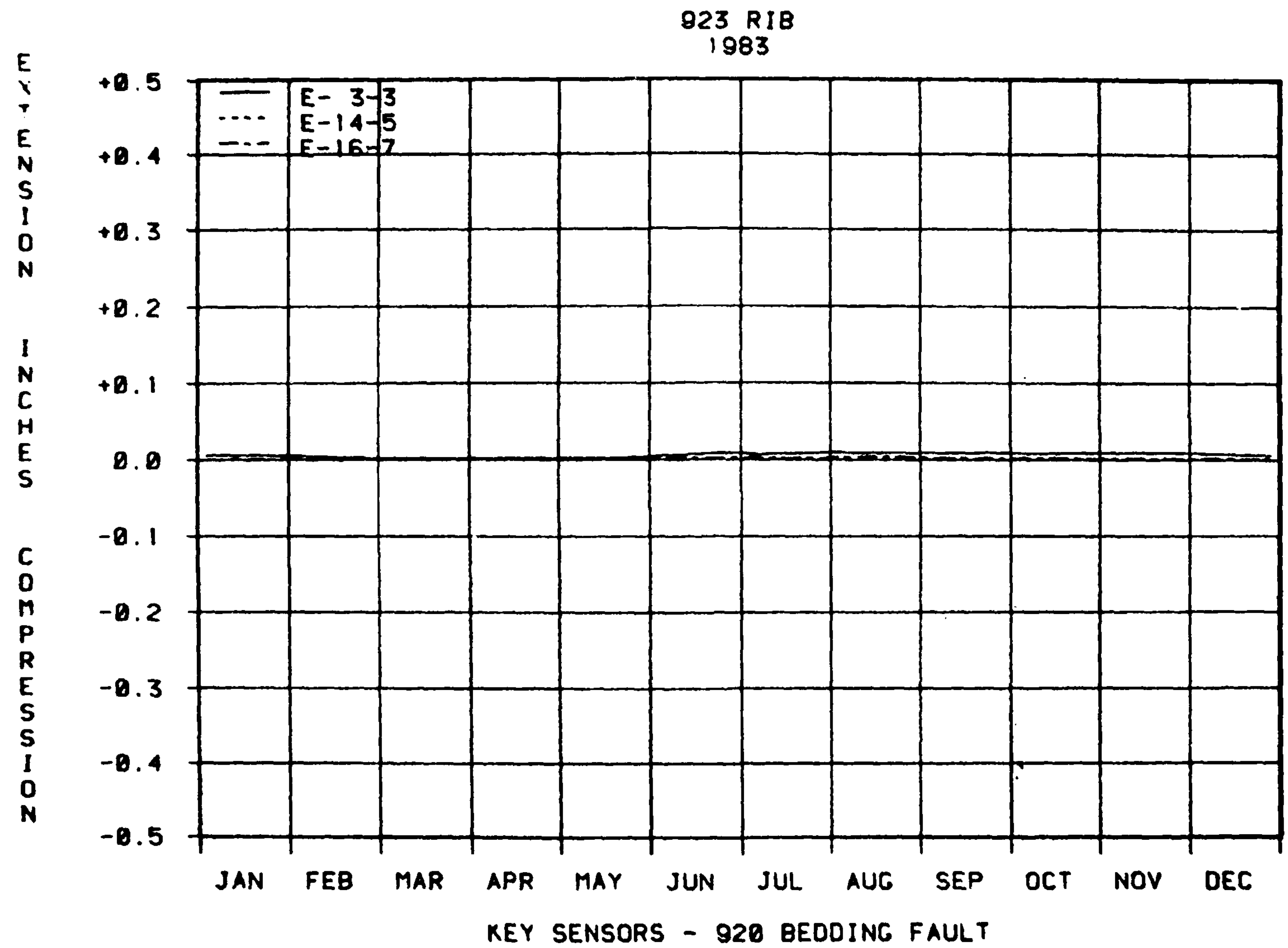

923 RIB
1983
E- 3-3
E-14-5
E-16-7
EXTENSION INCHES COMPRESSION
+0.5
+0.4
+0.3
+0.2
+0.1
0.0
-0.1
-0.2
-0.3
-0.4
-0.5
JAN FEB MAR APR MAY JUN JUL AUG SEP OCT NOV DEC
KEY SENSORS - 920 BEDDING FAULT

Fig 4.14d

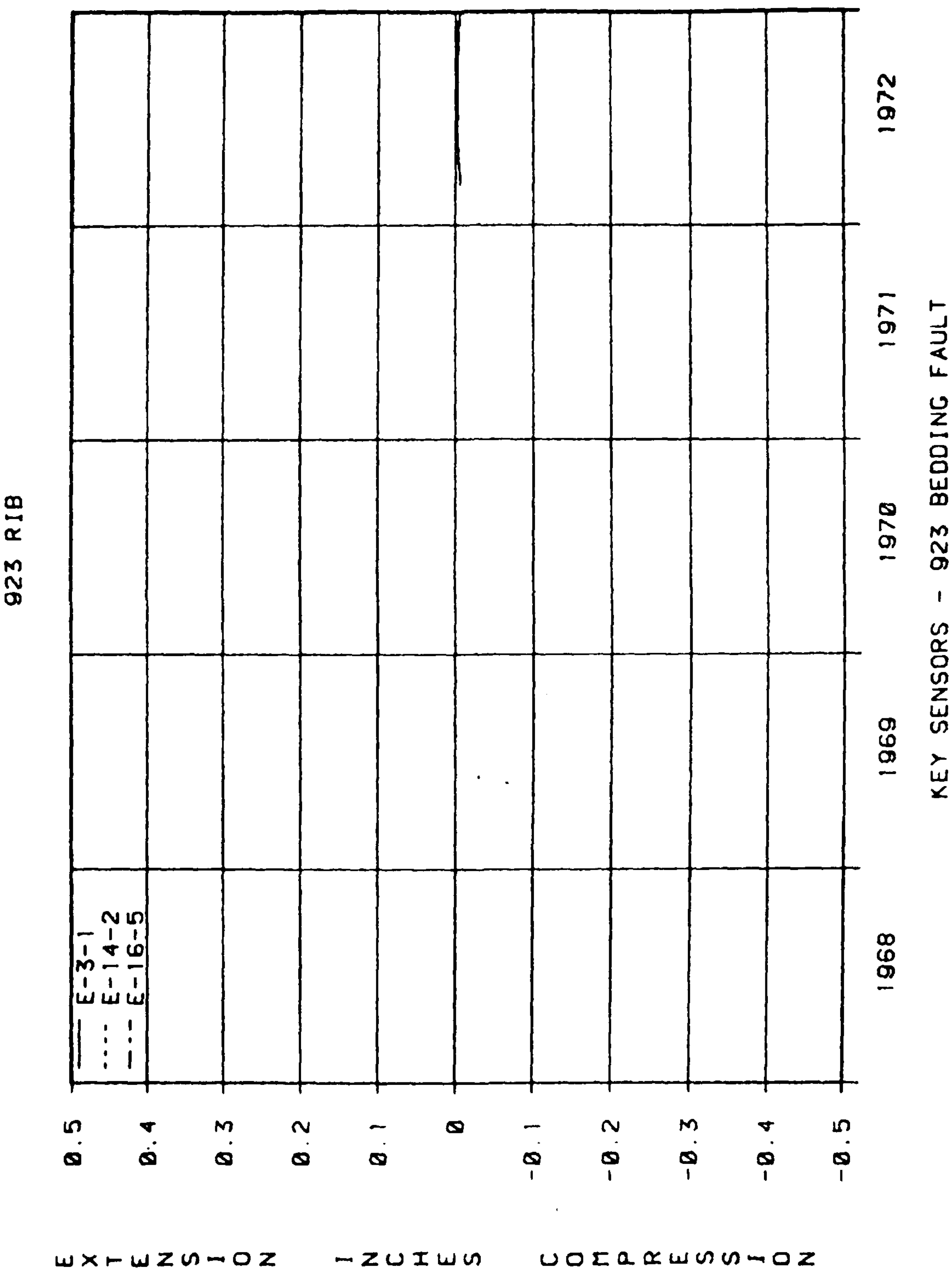

923 RIB
KEY SENSORS - 923 BEDDING FAULT
E-3-1
E-14-2
E-16-5
1968
1969
1970
1971
1972
0.5
0.4
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
-0.4
-0.5
EXTENSION INCHES COMPRESSION

Fig. 4.15a

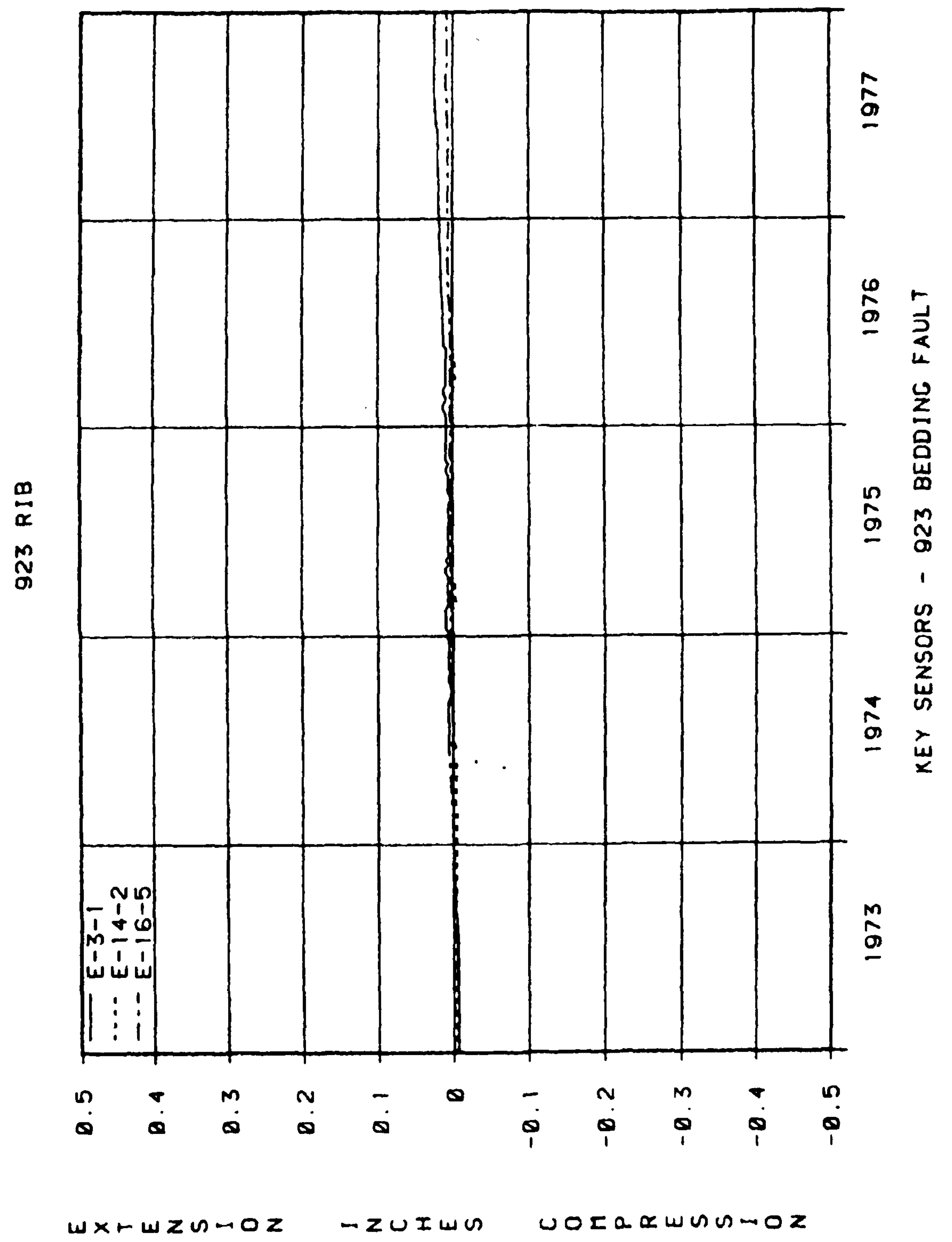
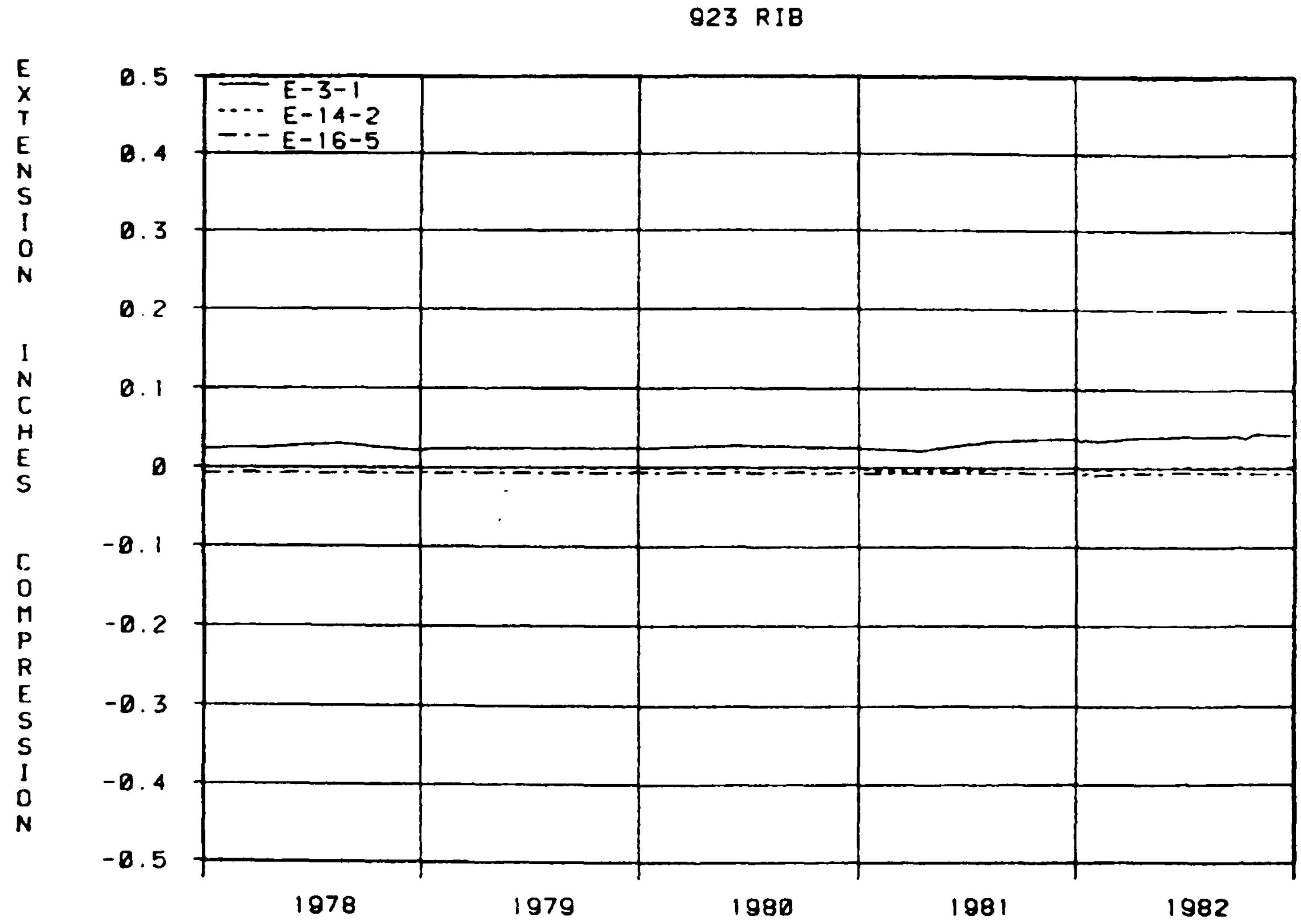
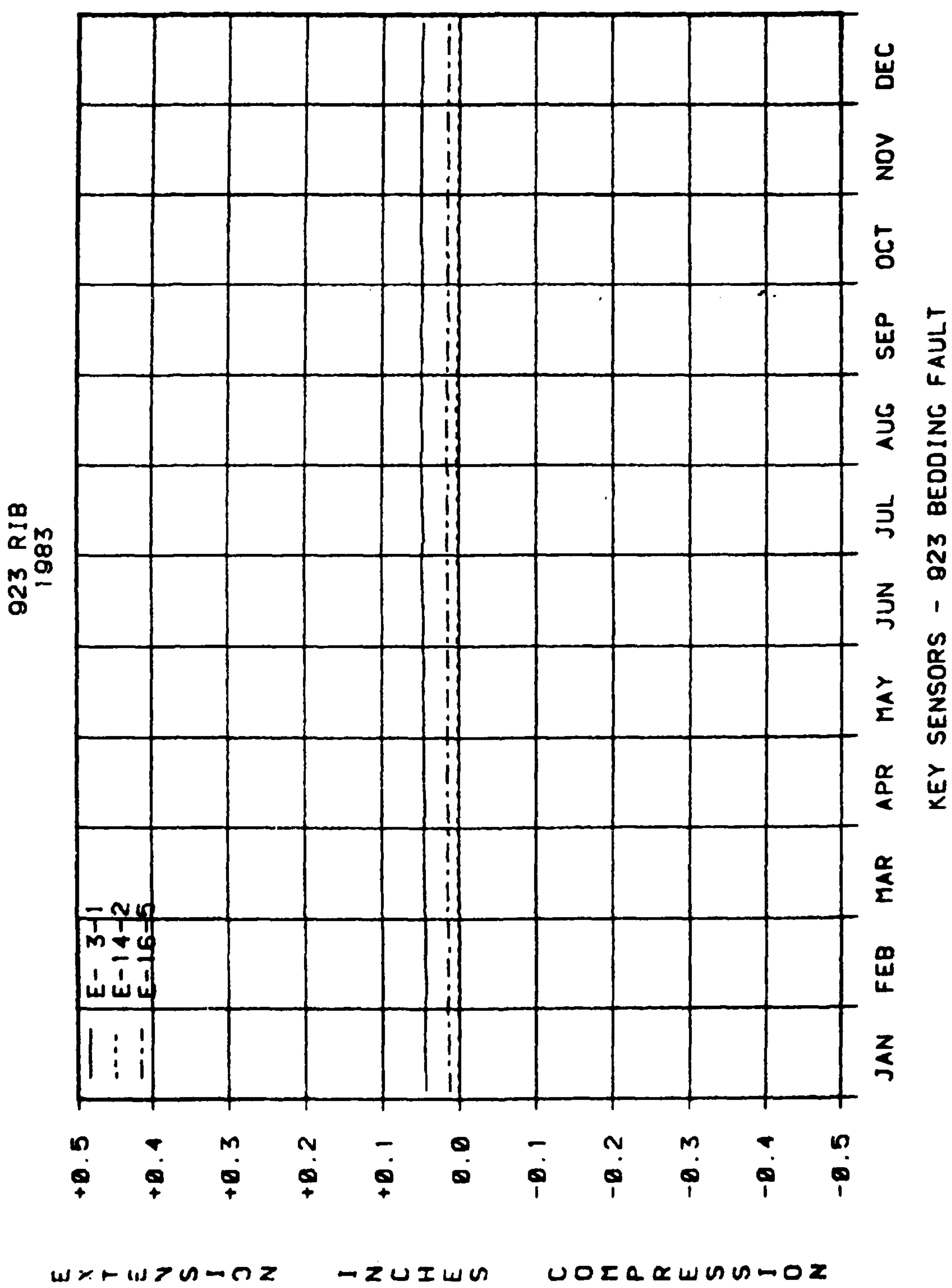

923 RIB
E-3-1
E-14-2
E-16-5
0.5
0.4
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
-0.4
-0.5
EXTENSION INCHES COMPRESSION
1973
1974
1975
1976
1977
KEY SENSORS - 923 BEDDING FAULT

Fig. 4.15b



KEY SENSORS - 923 BEDDING FAULT

Fig. 4.15c



923 RIB
1983
E- 3-1
E-14-2
E-16-5
JAN FEB MAR APR MAY JUN JUL AUG SEP OCT NOV DEC
+0.5 +0.4 +0.3 +0.2 +0.1 0.0 -0.1 -0.2 -0.3 -0.4 -0.5
EXTENSION INCHES COMPRESSION
KEY SENSORS - 923 BEDDING FAULT

Fig 4.15d

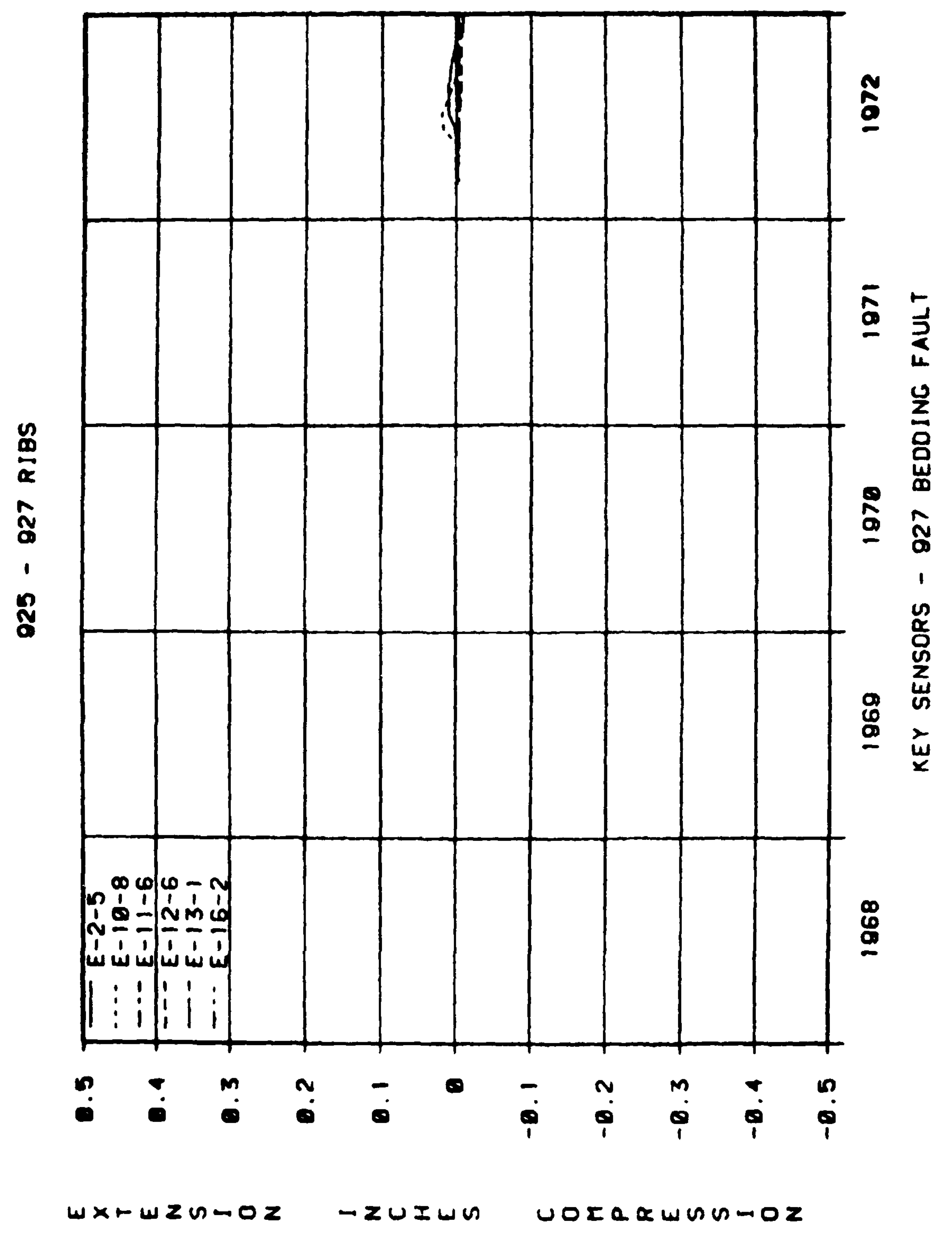
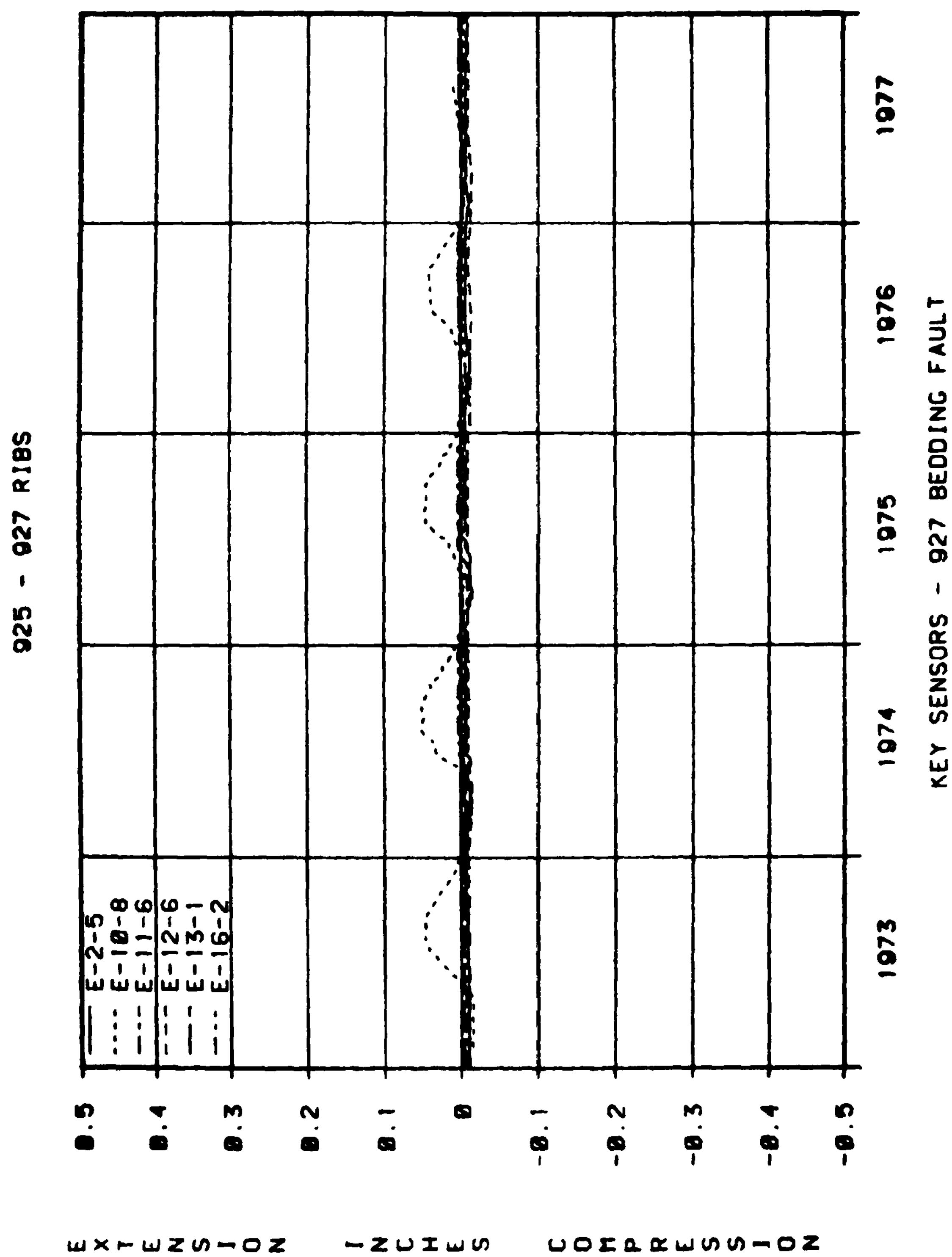

925 - 927 RIBS
KEY SENSORS - 927 BEDDING FAULT
1968
1969
1970
1971
1972
0.5
0.4
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
-0.4
-0.5
EXTENSION INCHES COMPRESSION
E-2-5
E-10-8
E-11-6
E-12-6
E-13-1
E-16-2

Fig. 4.16a



925 - 927 RIBS
KEY SENSORS - 927 BEDDING FAULT
E-2-5
E-10-8
E-11-6
E-12-6
E-13-1
E-16-2
0.5
0.4
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
-0.4
-0.5
1973
1974
1975
1976
1977
EXTENSION
INCHES
COMPRESSION

Fig. 4.16b

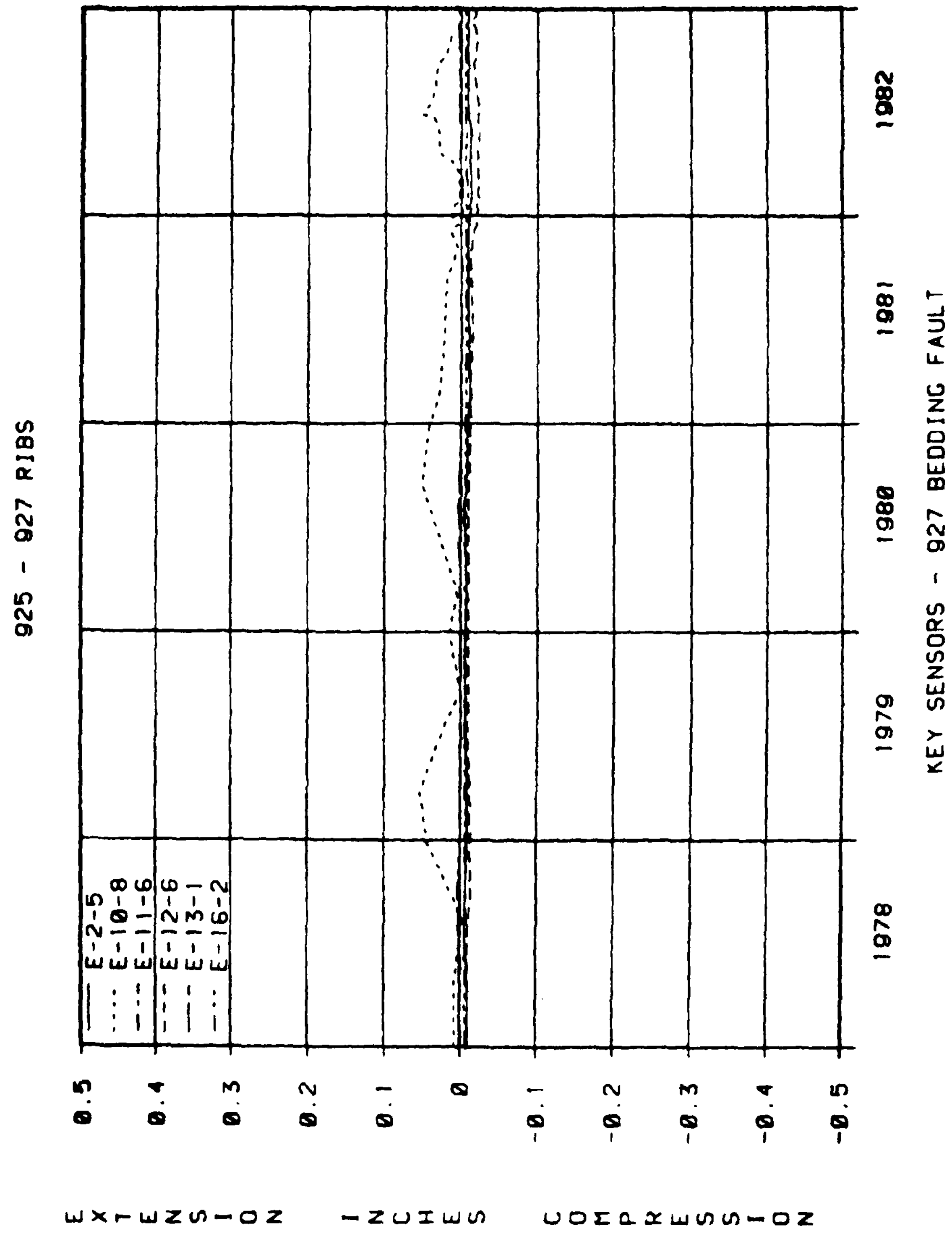

925 - 927 RIBS
KEY SENSORS - 927 BEDDING FAULT
E-2-5
E-10-8
E-11-6
E-12-6
E-13-1
E-16-2
1978
1979
1980
1981
1982
0.5
0.4
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
-0.4
-0.5
EXTENSION
INCHES
COMPRESSION

Fig. 4.16c

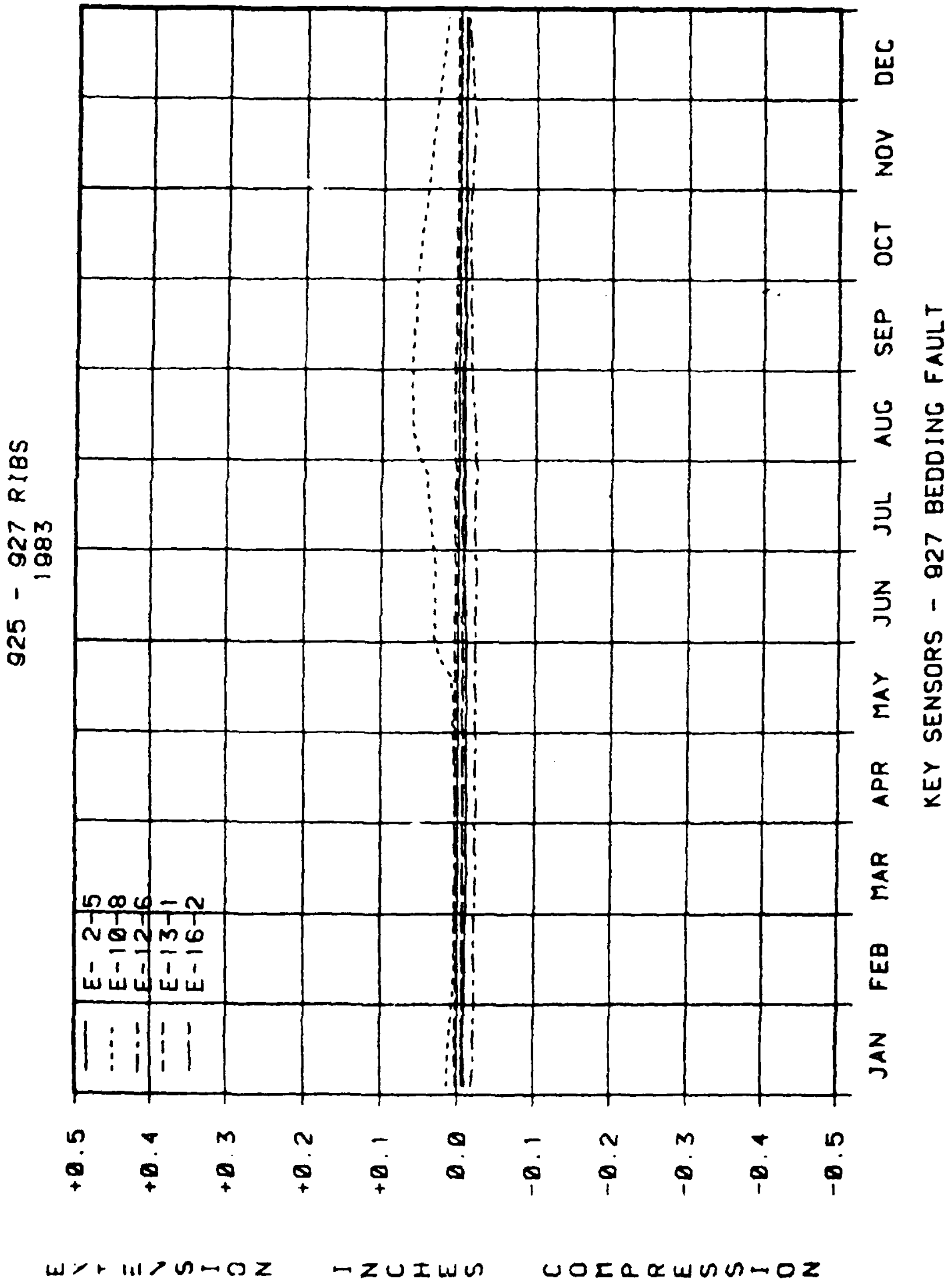

925 - 927 RIBS
1983
KEY SENSORS - 927 BEDDING FAULT
E- 2-5
E-10-8
E-12-6
E-13-1
E-16-2
JAN FEB MAR APR MAY JUN JUL AUG SEP OCT NOV DEC
+0.5 +0.4 +0.3 +0.2 +0.1 0.0 -0.1 -0.2 -0.3 -0.4 -0.5
EXTENSION INCHES COMPRESSION

Fig 4.16d

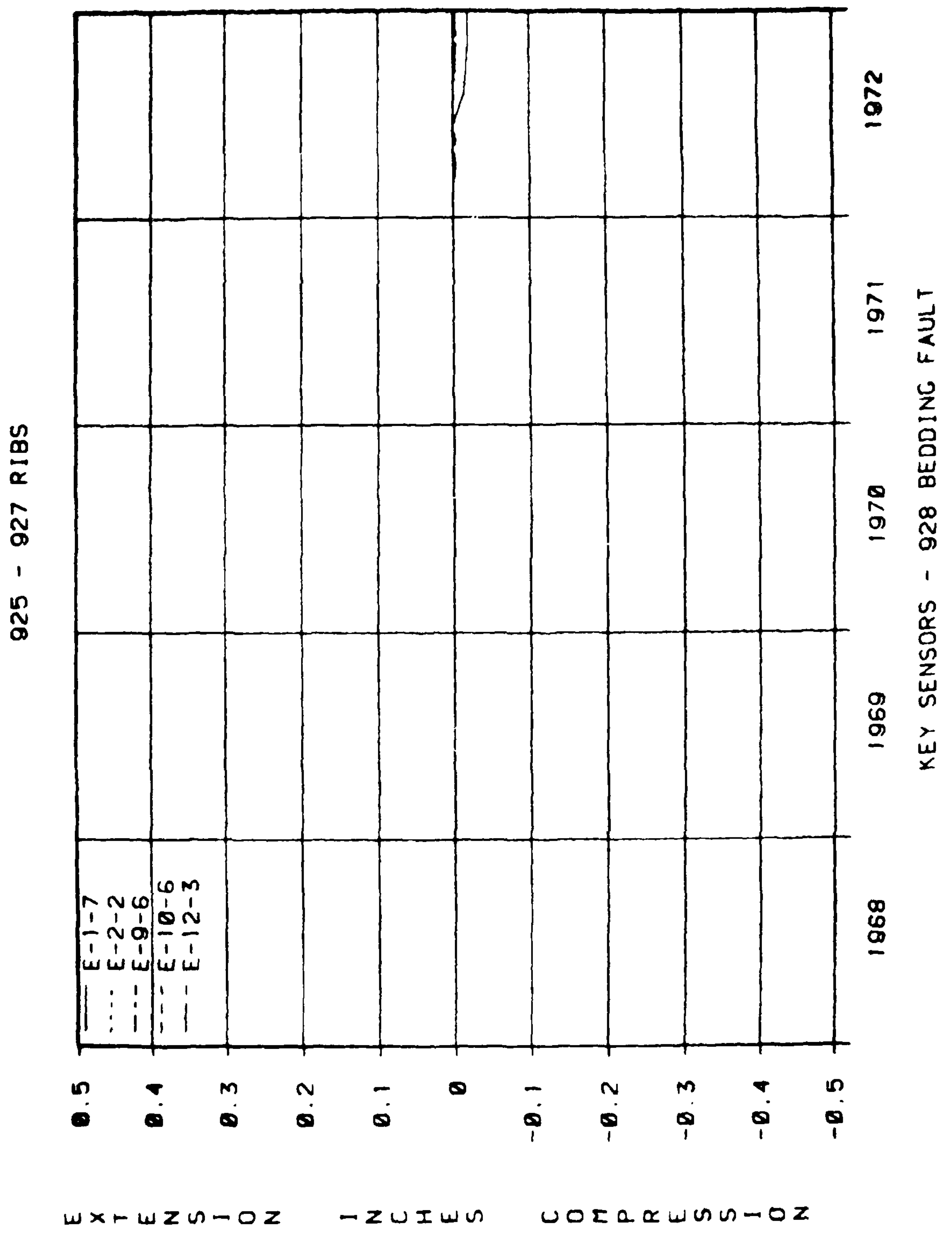

925 - 927 RIBS
E-1-7
E-2-2
E-9-6
E-10-6
E-12-3
0.5
0.4
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
-0.4
-0.5
EXTENSION INCHES COMPRESSION
1968
1969
1970
1971
1972
KEY SENSORS - 928 BEDDING FAULT

Fig. 4.17a

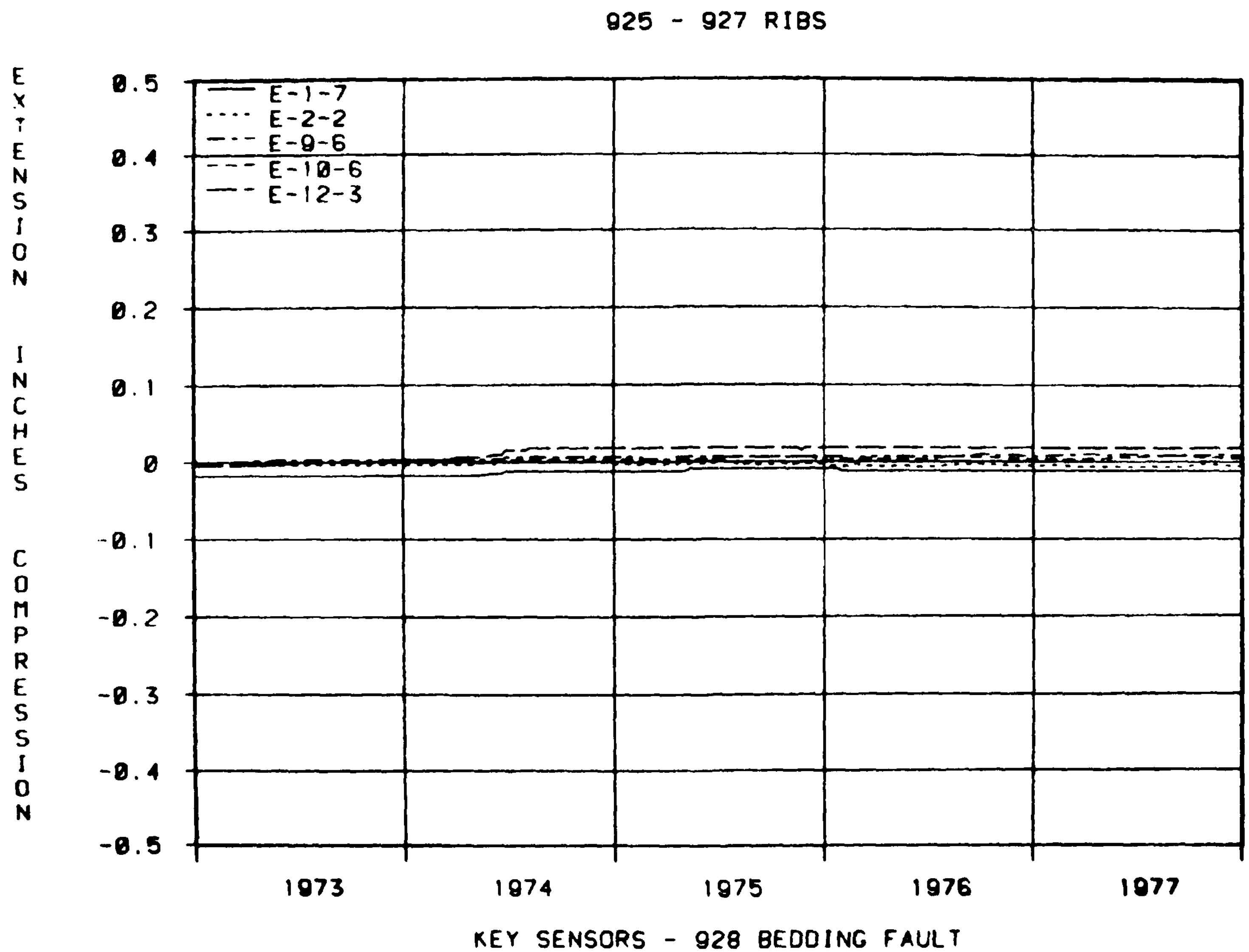

925 - 927 RIBS
E-1-7
E-2-2
E-9-6
E-10-6
E-12-3
0.5
0.4
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
-0.4
-0.5
EXTENSION INCHES COMPRESSION
1973
1974
1975
1976
1977
KEY SENSORS - 928 BEDDING FAULT

Fig. 4.17b

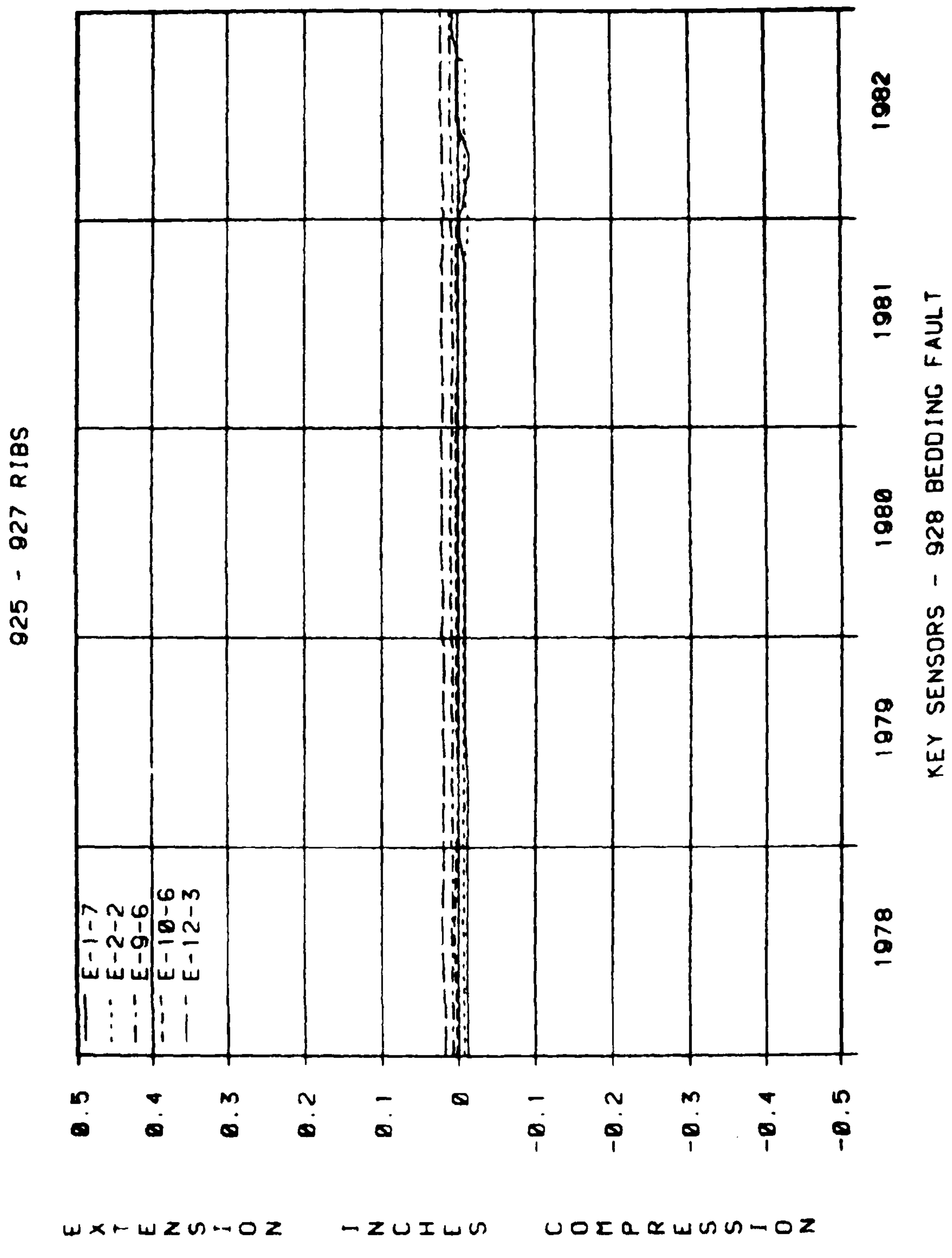

925 - 927 RIBS
KEY SENSORS - 928 BEDDING FAULT
E-1-7
E-2-2
E-9-6
E-10-6
E-12-3
1978
1979
1980
1981
1982
0.5
0.4
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
-0.4
-0.5
EXTENSION INCHES COMPRESSION

Fig. 4.17c

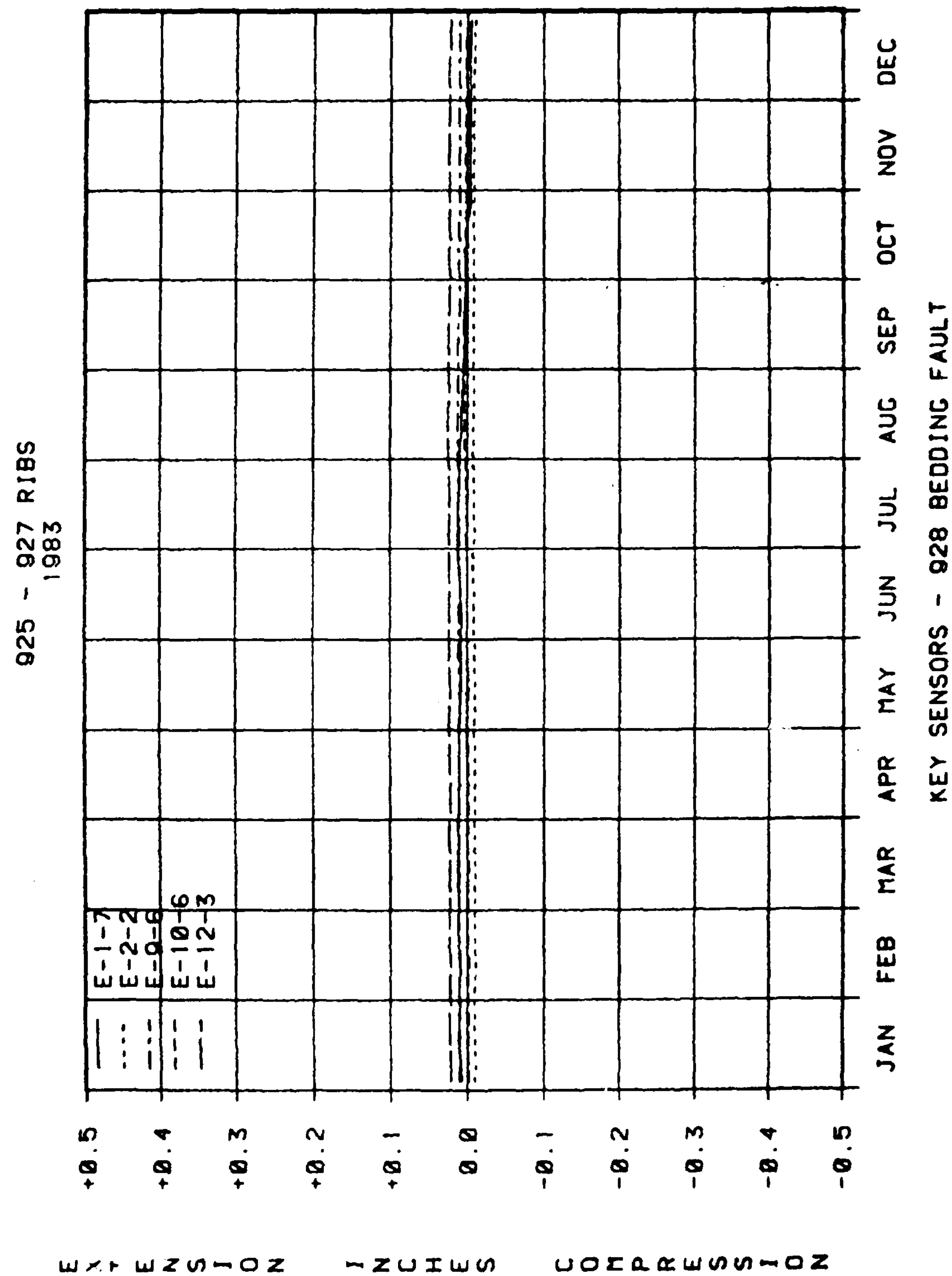

925 - 927 RIBS
1983
KEY SENSORS - 928 BEDDING FAULT
JAN FEB MAR APR MAY JUN JUL AUG SEP OCT NOV DEC
+0.5 +0.4 +0.3 +0.2 +0.1 0.0 -0.1 -0.2 -0.3 -0.4 -0.5
EXTENSION INCHES COMPRESSION
E-1-7
E-2-2
E-9-6
E-10-6
E-12-3

Fig 4.17d

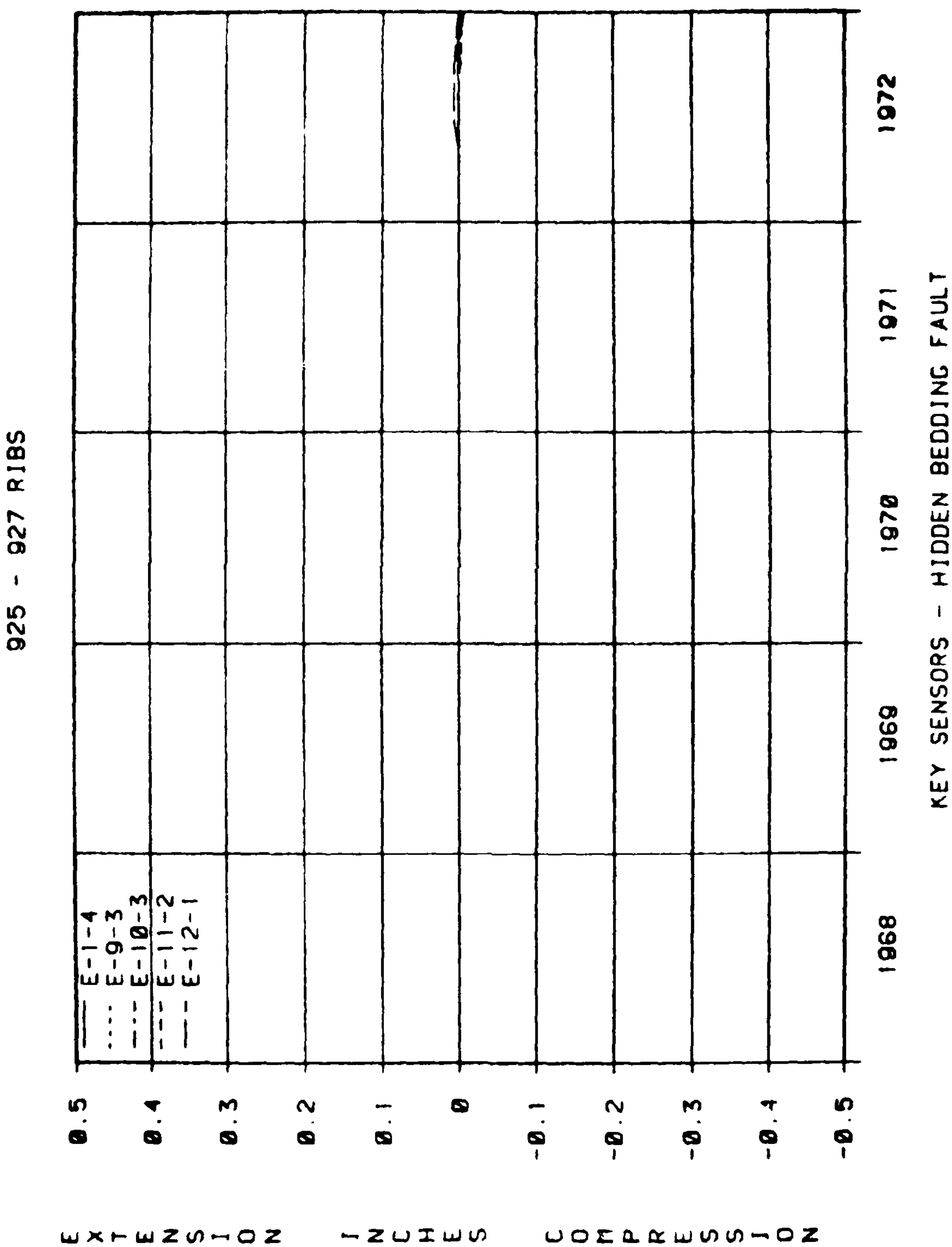

925 - 927 RIBS
KEY SENSORS - HIDDEN BEDDING FAULT
E-1-4
E-9-3
E-10-3
E-11-2
E-12-1
1968
1969
1970
1971
1972
0.5
0.4
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
-0.4
-0.5
EXTENSION
INCHES
COMPRESSION

Fig. 4.18a

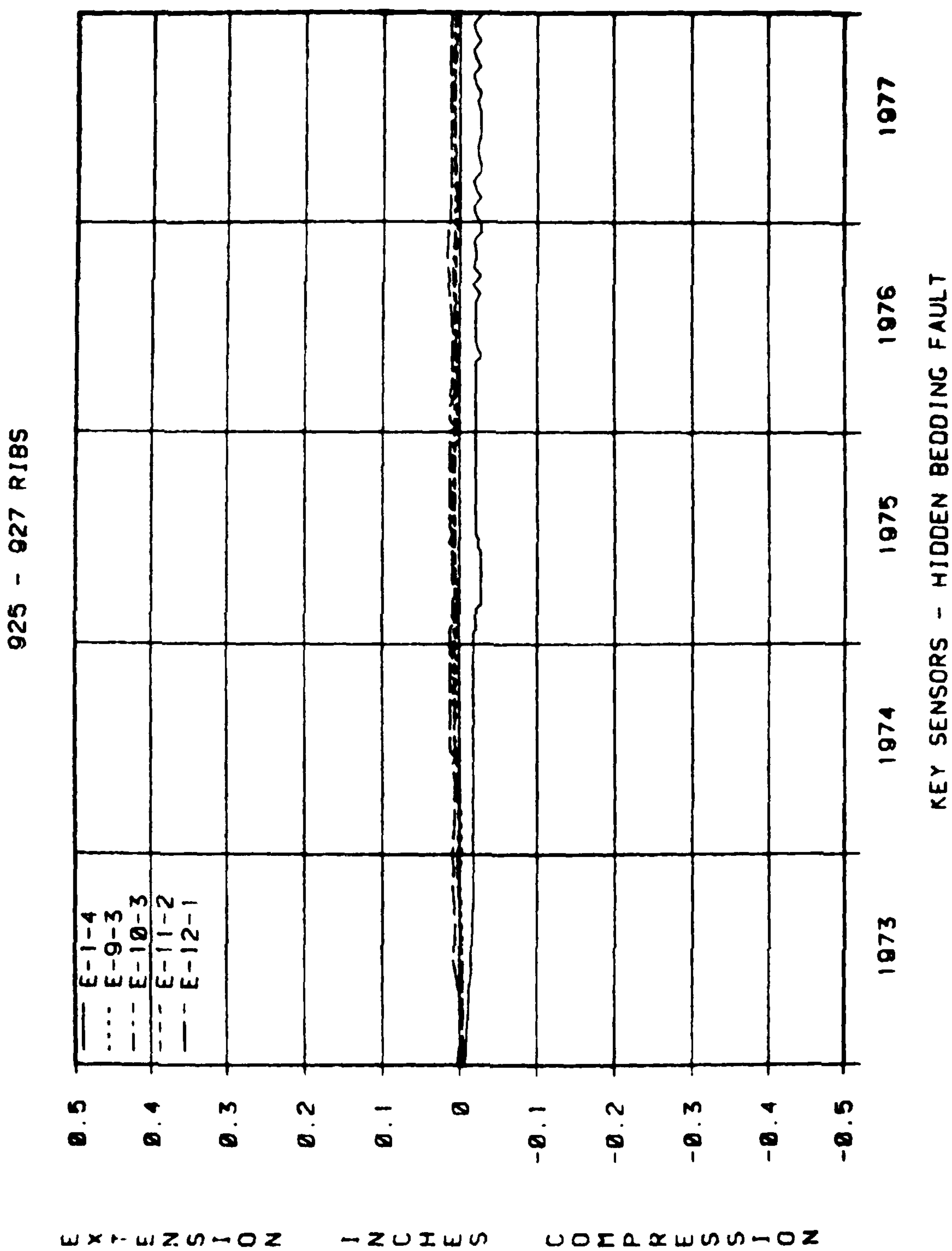

925 - 927 RIBS
E-1-4
E-9-3
E-10-3
E-11-2
E-12-1
1973
1974
1975
1976
1977
KEY SENSORS - HIDDEN BEDDING FAULT
0.5
0.4
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
-0.4
-0.5
EXTENSION INCHES COMPRESSION

Fig. 4.18b

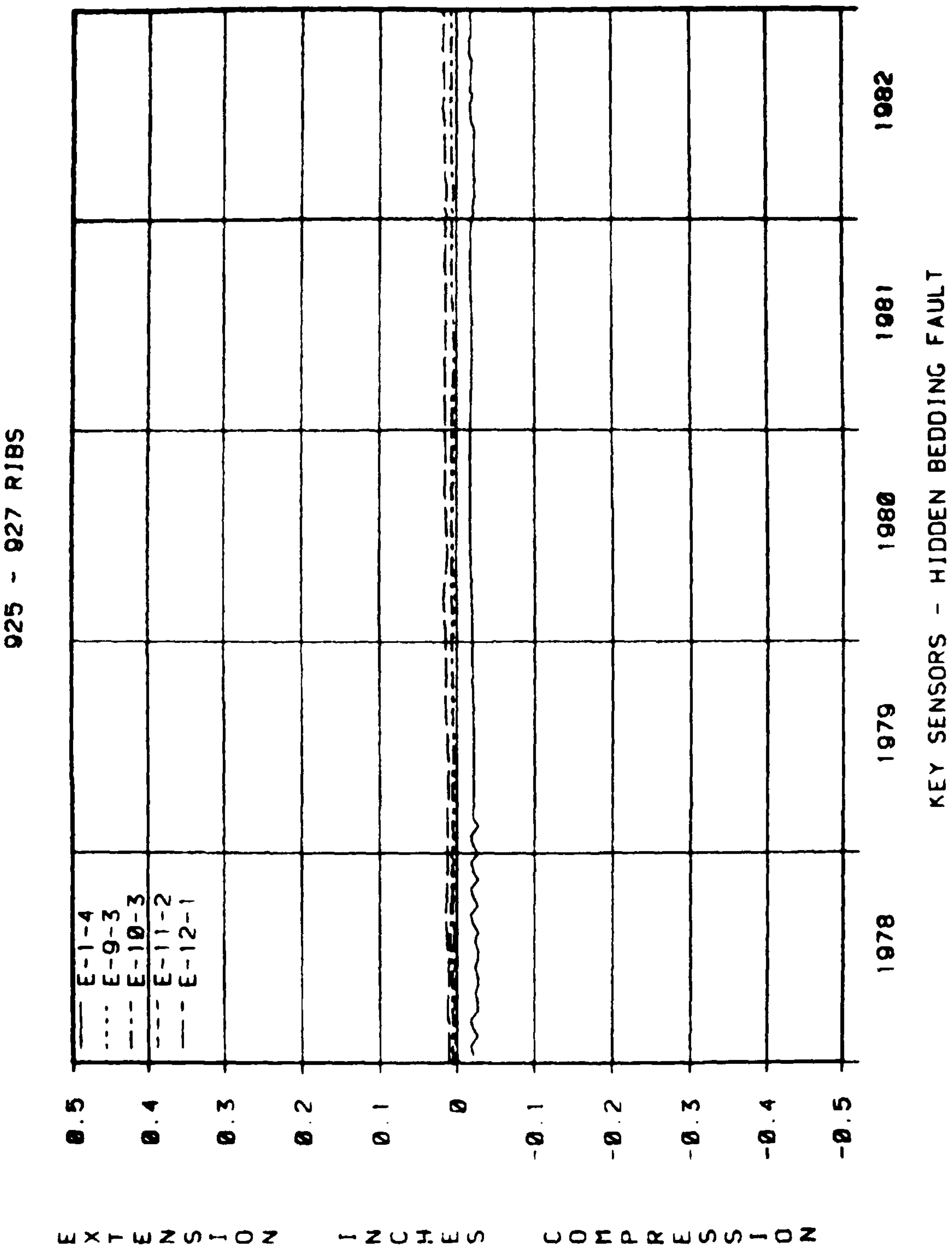
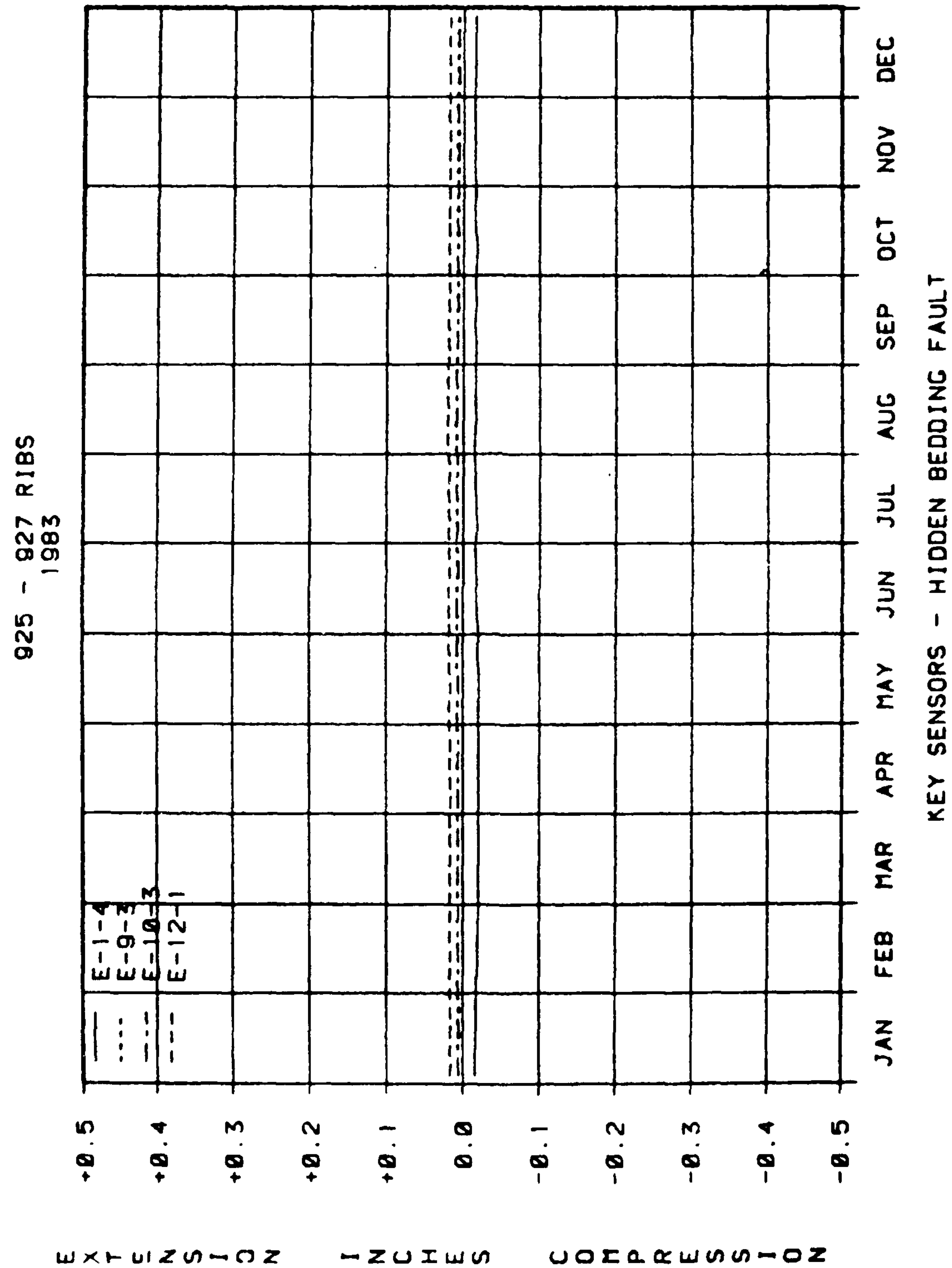

925 - 927 RIBS
KEY SENSORS - HIDDEN BEDDING FAULT
E-1-4
E-9-3
E-10-3
E-11-2
E-12-1
1978
1979
1980
1981
1982
0.5
0.4
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
-0.4
-0.5
EXTENSION INCHES COMPRESSION

Fig. 4.18c



925 - 927 RIBS
1983
KEY SENSORS - HIDDEN BEDDING FAULT
E-1-4
E-9-3
E-10-3
E-12-1
JAN FEB MAR APR MAY JUN JUL AUG SEP OCT NOV DEC
+0.5 +0.4 +0.3 +0.2 +0.1 0.0 -0.1 -0.2 -0.3 -0.4 -0.5
EXTENSION INCHES COMPRESSION

Fig 4.18d

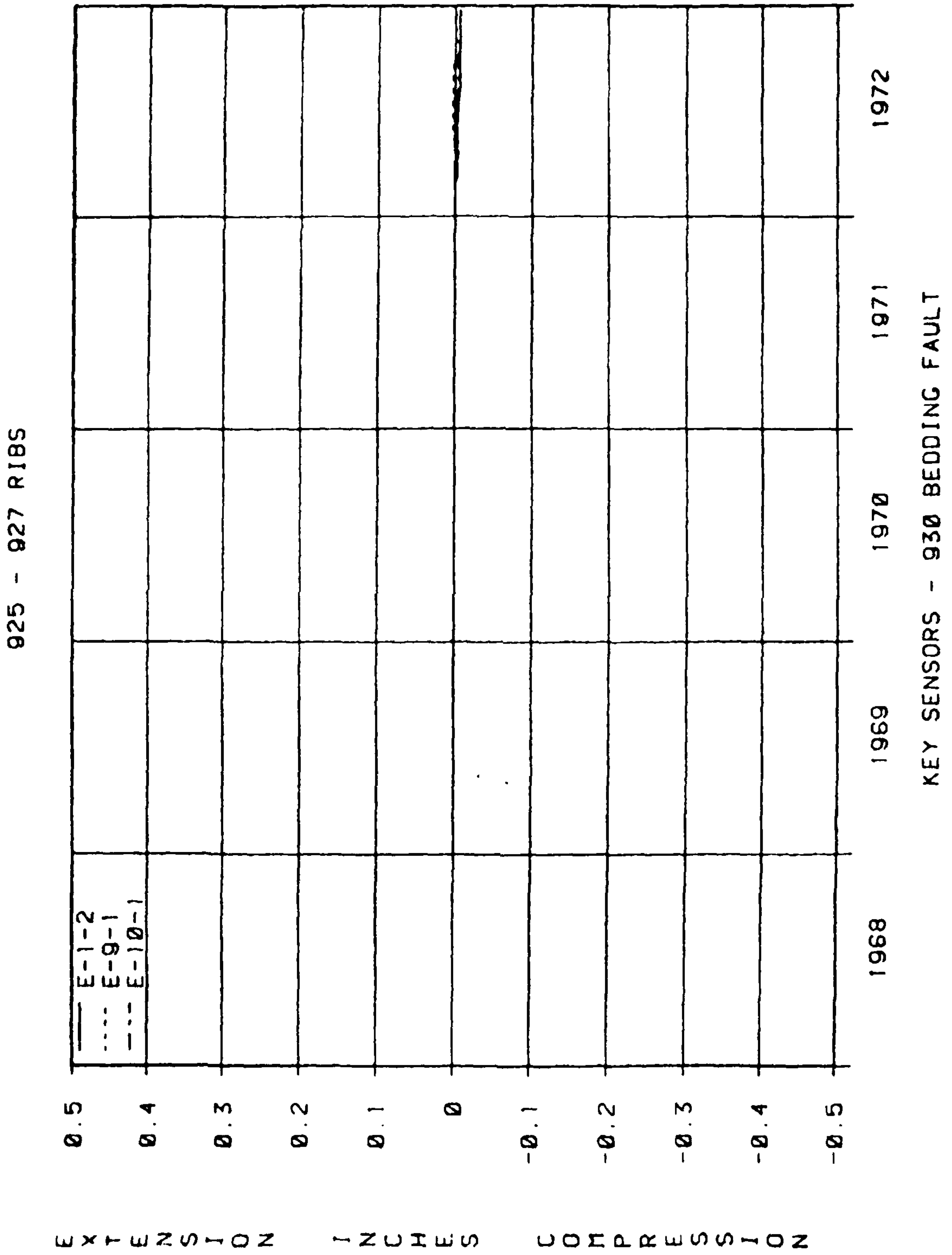

925 - 927 RIBS
KEY SENSORS - 930 BEDDING FAULT
E-1-2
E-9-1
E-10-1
1968
1969
1970
1971
1972
0.5
0.4
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
-0.4
-0.5
EXTENSION INCHES COMPRESSION

Fig. 4.19a

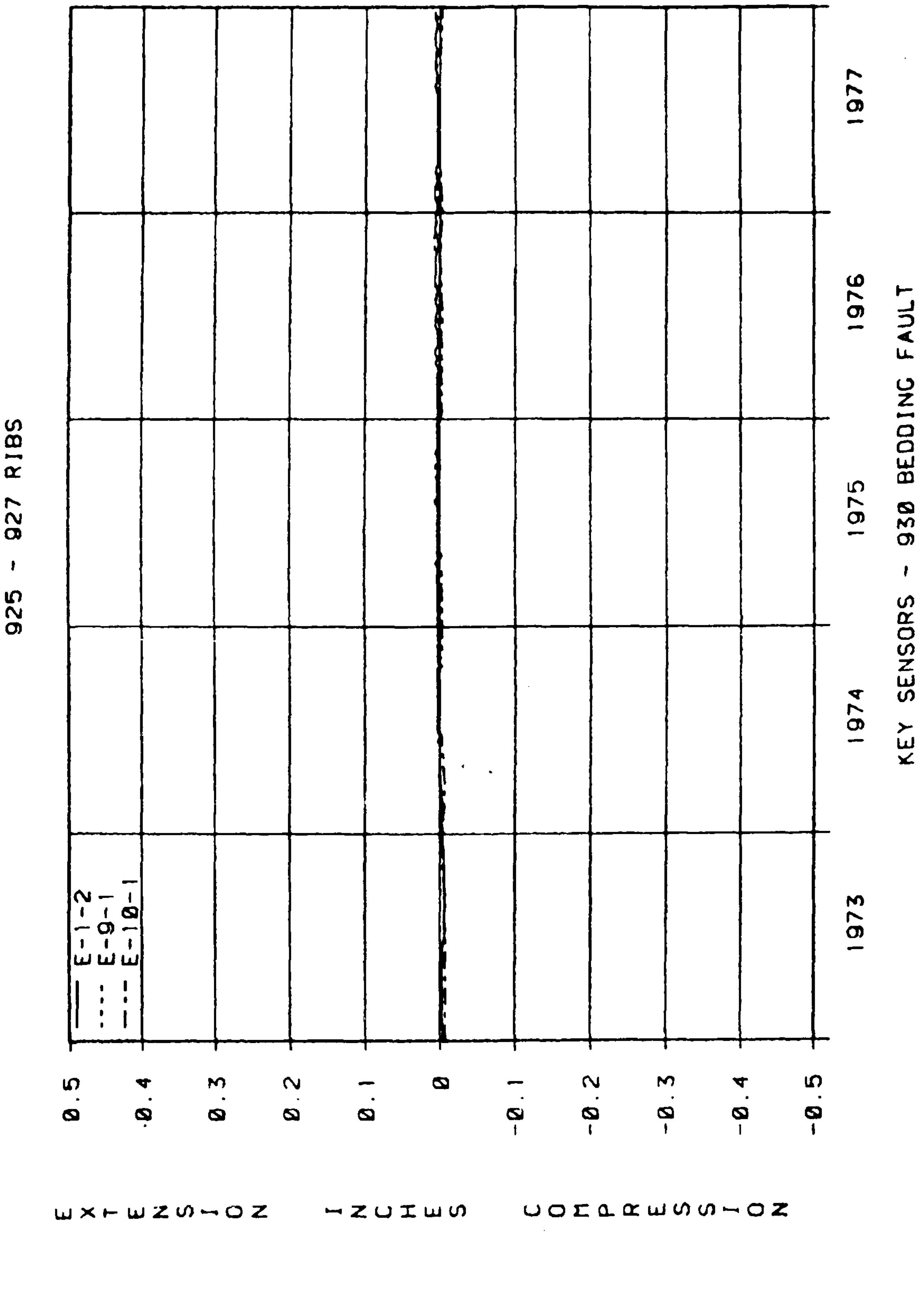

925 - 927 RIBS
KEY SENSORS - 930 BEDDING FAULT
E-1-2
E-9-1
E-10-1
0.5
0.4
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
-0.4
-0.5
1973
1974
1975
1976
1977
EXTENSION
INCHES
COMPRESSION

Fig. 4.19b

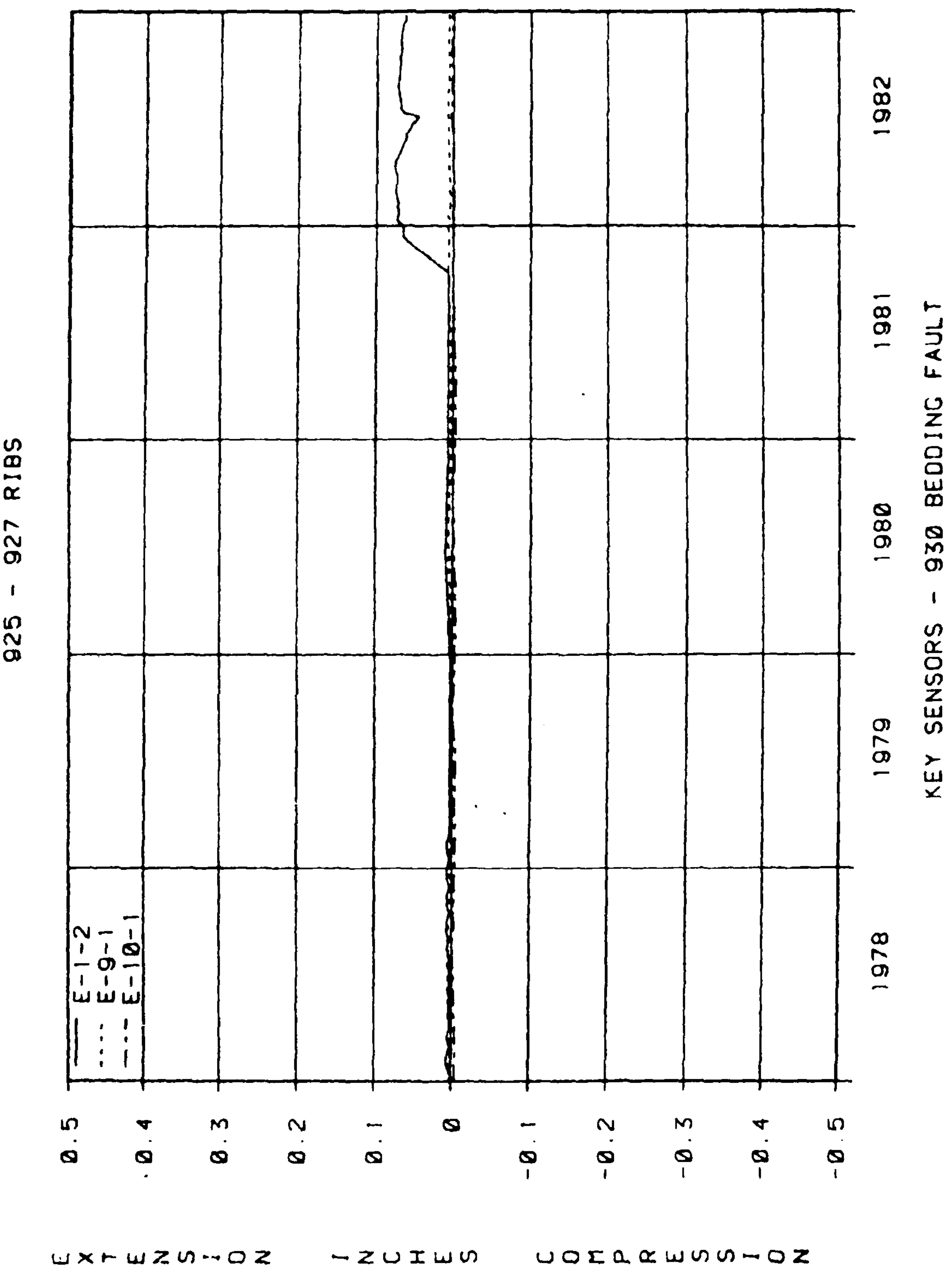
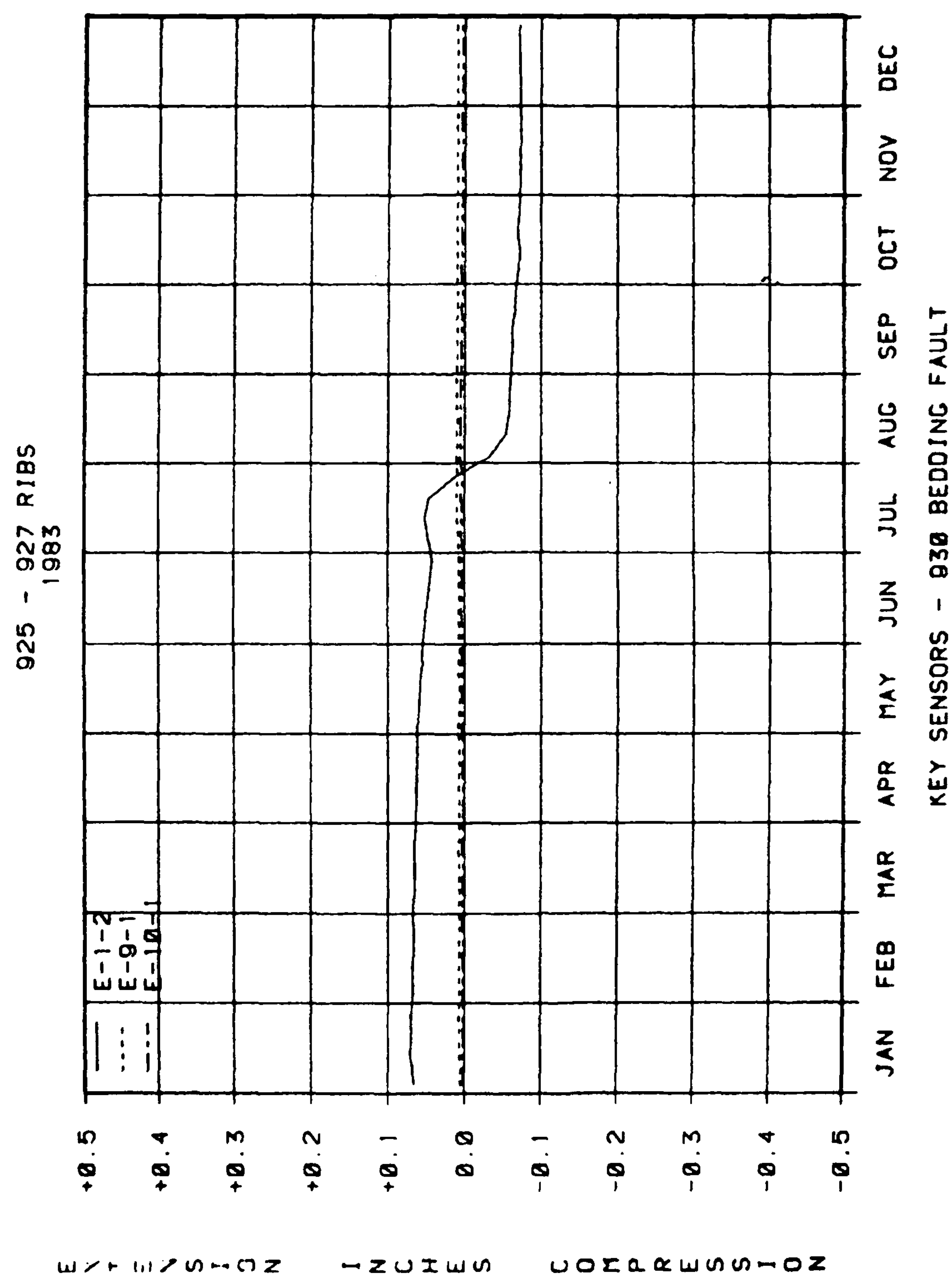

925 - 927 RIBS
KEY SENSORS - 930 BEDDING FAULT
E-1-2
E-9-1
E-10-1
1978
1979
1980
1981
1982
0.5
0.4
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
-0.4
-0.5
EXTENSION
INCHES
COMPRESSION

Fig. 4.19c



925 - 927 RIBS
1983
KEY SENSORS - 930 BEDDING FAULT
E-1-2
E-9-1
E-10-1
JAN FEB MAR APR MAY JUN JUL AUG SEP OCT NOV DEC
+0.5 +0.4 +0.3 +0.2 +0.1 0.0 -0.1 -0.2 -0.3 -0.4 -0.5
EXTENSION INCHES COMPRESSION

Fig 4.19d

SECTION 5. CONCLUSIONS

5.01 General.

a. The unique geometry of the geologic structure on the Left Bank Slope causes it to be an area favorable to failure of large rock masses. After partial failure of the undercut Left Abutment Rib in 1971, a portion of the rib upstream from the failure was reinforced by installation of cable tendons. The entire Left Bank Slope was treated by placement of a shot-rock buttress at the toe of the slope, below elevation 2,500 feet, numerous drain holes were drilled in four of the five rock ribs and an extensive instrumental monitoring system was emplaced.

b. In this area there is abundant evidence in the geologic record of historic failure of rock masses by both creep and rapid rock slide. Thus, it is logical that the slope was in a mode of adjustment to the present valley configuration prior to construction of the project. The placement of the shot-rock buttress was intended to mitigate effects of the reservoir on stability in the toe area, however, no studies have been conducted regarding the performance of the present slope under conditions imposed by the current design earthquake nor have studies been made as to the effect of failure of rock masses high on the slope.

c. Consequences of failure could vary from a temporary closing of Montana State Highway 37 to significant wave run-up in the reservoir in the vicinity of the dam. Little flood wave damage would be expected downstream from the project, even at maximum reservoir level. Under a "worst case" scenario, project facilities might suffer damage in terms of spillway gates, powerhouse, and abutment facilities. Our best judgement on known conditions in the left abutment is that failure of this rib would probably not fail the dam, but could deposit a large rock mass against the upstream face leading to stability criteria violations. The principal danger is potential loss of life and property for any of the traveling public trapped beneath a slide or in nearby areas adjacent to the reservoir. Much of this potential has been mitigated by installation of an automatic warning system on the highway below the Left Abutment Rib together with maintenance of a quality instrumentation system and proper evaluation of instrumental data.

5.02 Left Abutment Rib. "Step" movement on the Dirty Shame Bedding Fault high on the rib indicates continuing downslope adjustment both upstream and downstream of the A Joint in areas little affected or unaffected by the tendons. This movement has been episodic since mid-1980. While it shows no sign of accelerating, such as might be expected of imminent failure, neither is there any sign of abatement. Low on the rib, there is every instrumental indication that the tendons are either effective or perhaps unnecessary insofar as the Dirty Shame is concerned. However, there are several indications low on the slope that the strains in the rock mass may be attempting to "out flank" the tendons. The extension across the North-South Tension Joint below the Dirty Shame upstream from the A Joint and the long-term expansion across the

Dirty Shame downstream from the A Joint are suggestive of this. On a smaller scale, there is evidence of extension across the DS+80 and C-C Prime Joint on the slope including one of the instruments crossing the DS+80 in the tendon field (L-17). This suggests that the DS+80/C-C Prime wedge is, in part, adjusting slightly towards the cut face in spite of the tendons. There are also indications late in 1983 that the whole DS/C block may be involved. Some extension of what is interpreted as smaller face blocks upstream from the D Joint is indicated. The apparent very small long-term downslope creep indicated at great depths in inclinometer NI-5, and the more recent extension registered deep dehind the toe of the slope in extensometer L-13 suggest that movement is occurring, however small, of a rock mass which extends well below the Dirty Shame Bedding Fault. These developments will be very closely watched. Close monitoring of this rib should continue with addition of instruments as needed.

5.03 Upstream (914, 923, 925, and 927) Ribs. The present vertical extensometer system indicates no sign of instability of any of these ribs. These instruments have reached their projected life span and replacement by nearly horizontal extensometers has begun and should continue upslope so to monitor potential failure of higher portions of these ribs not buttressed by the rockfill within the reservoir.

5.04 Summary. The stability problems of this area were recognized, evaluated, and dealt with by the designers, Board of Consultants and higher authority. Consequences of failure are not possible to accurately predict, but reasonable precautions have been taken with defensive measures in place, and there are no data to indicate the slope is in peril of imminent failure. However, the observed "creep type" movement in certain portions of the slope is indicative of marginal stability conditions, and dictates the need for continuing observation and interpretation from a reliable instrumentation system. We conclude the instrumentation has been an effective tool to measure the slope's reaction to imposed forces and that it should be maintained, continued, and modified for the life of tne project.

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Appendix A - Instrument Diagrams

APPENDIX A

1. <u>Instrumental Legend</u>.

E	Vertical tandum rod extensometer (SINCO type).
L	Near horizontal multiple point borehole extensometer (MPBX), wire or rod type, Terrametrics type.
X	Short rod extensometer, Corps of Engineers/Pacific-Western Engineering type.
PE	Electric piezometer (Geonore type)
PP	Pneumatic piezometer (SINCO type)
PEP	Redundant installation of electric and pneumatic piezometers.
PEN	Installation of electric piezometers and rock noise sensors (the latter abandoned).
NI	Borings established for moveable rock noise sensors (now abandoned and inclinometer measurements.

2. <u>Geologic Legend</u>.

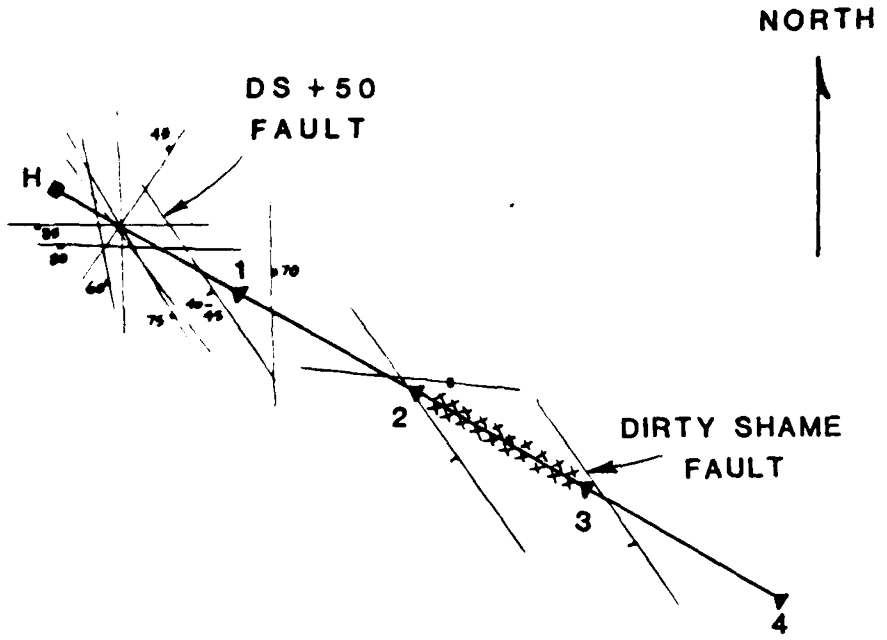
DS	Dirty Shame Bedding Fault
DS+7	Dirty Shame plus 7 Bedding Fault
DS+50	Dirty Shame plus 50 Bedding Fault
DS+80	Dirty Shame plus 80 Bedding Fault
DS+122	Dirty Shame plus 122 Bedding Fault
A	A Joint
C	C Joint
C'	C Prime Joint
D	D Joint (zone)
E	E Joint (zone)
F	F Joint (zone)
G	G Joint
N-S Tension Joint	North-South Joint between D and C' joints manifest by tension cracks across face of DS+122.
N-S	Undesignated north-south striking joint.
E-W	Undesignated east-west striking joint.
Bdng	Undesignated bedding joint or fault

3. <u>Measurement Definitions</u>.

<u>Displacement</u>: Measured displacement of segment of boring from top to bottom of one rod or wire as indicated by single transducer or vernier.

Delta Displacement: The arithmetical displacement between successively deeper anchors in a MPBX (L extensometer). All E extensometers show delta displacement only.

Floating Head: The arithmetical displacement between the deepest anchor and successively shallower anchors. Assumes the deepest anchors. Assumes the deepest anchor to be fixed and all other anchors moving relative to it.



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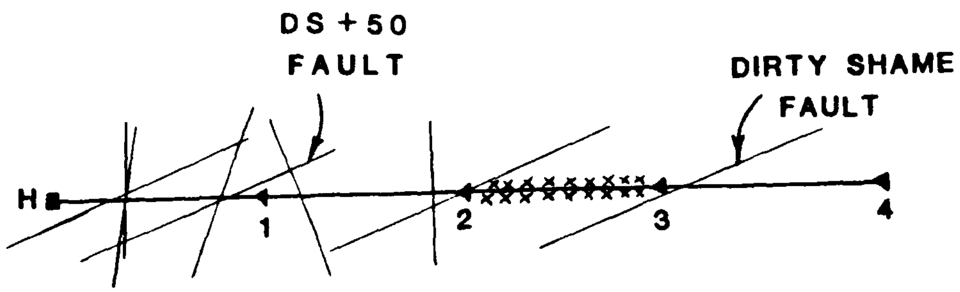

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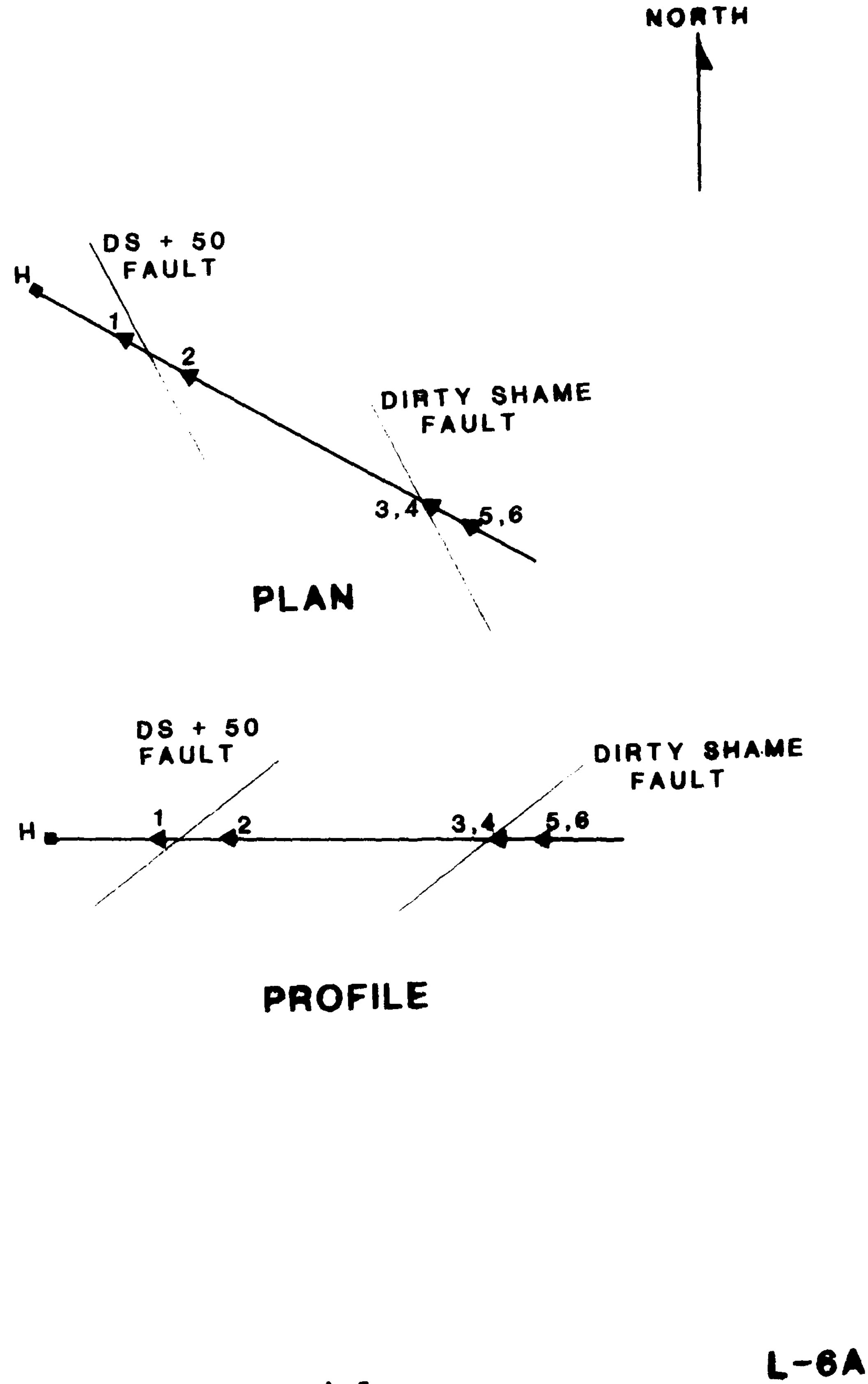
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DS + 50
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DIRTY SHAME
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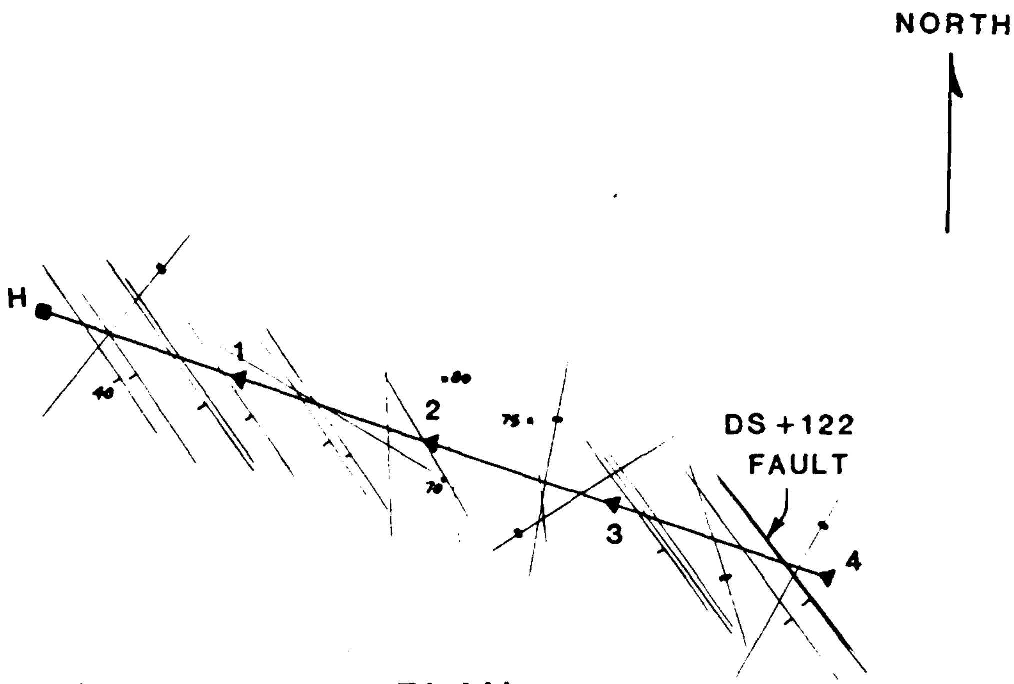
PROFILE
L-6A



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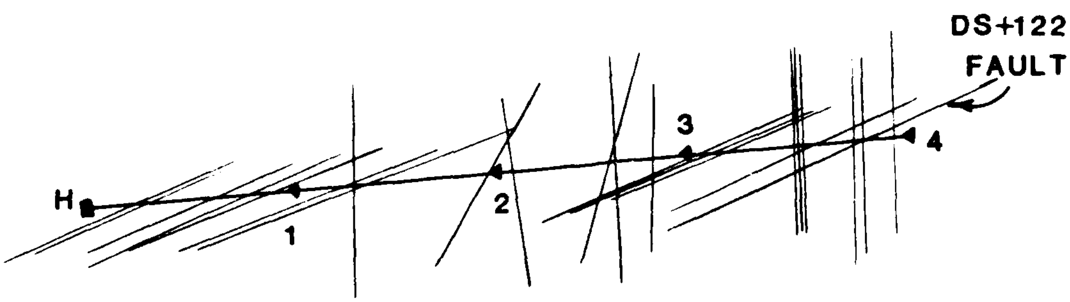

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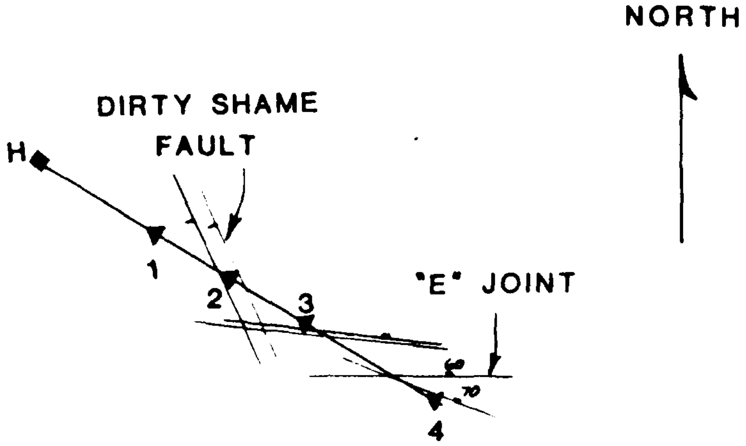

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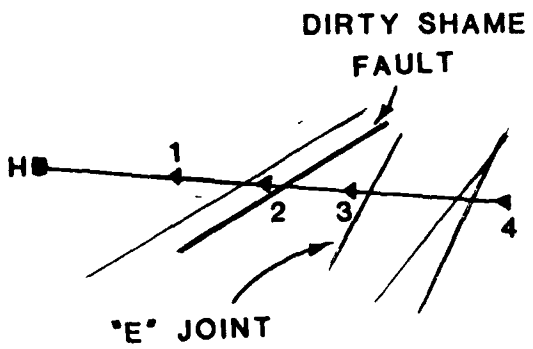

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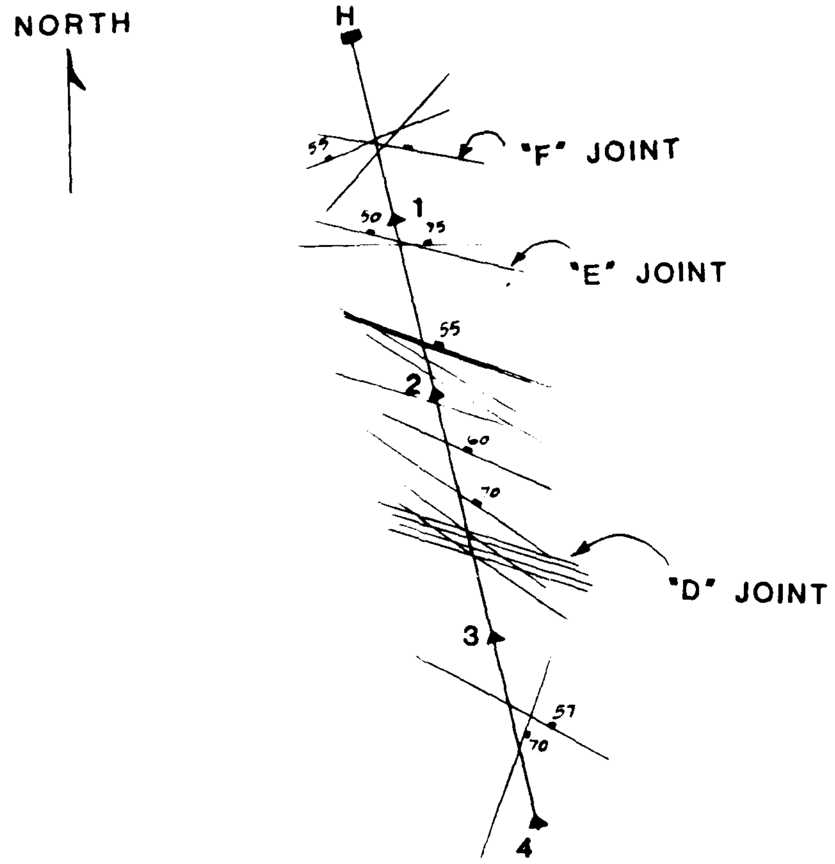

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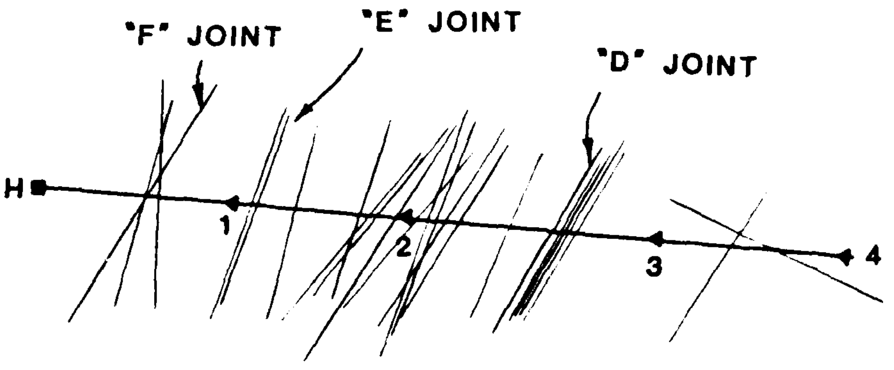

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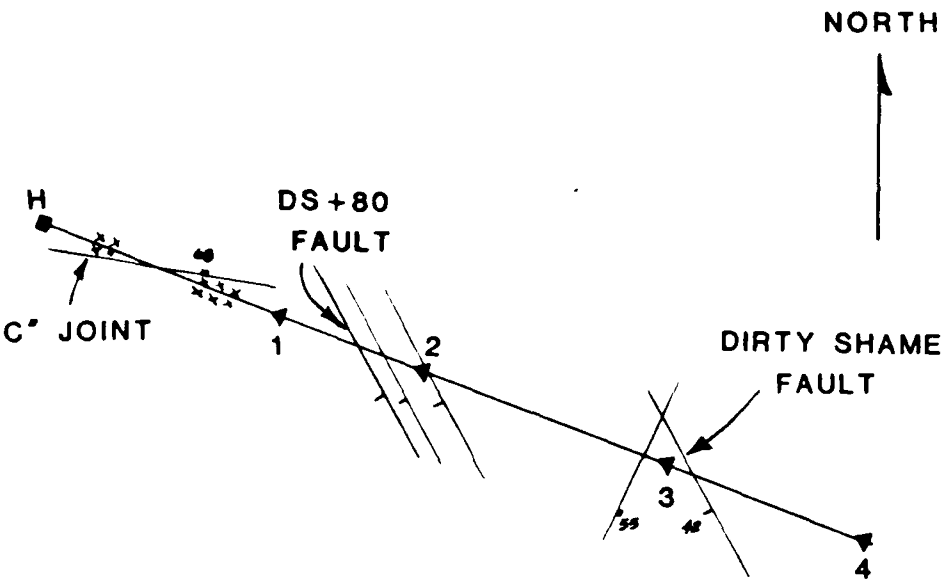

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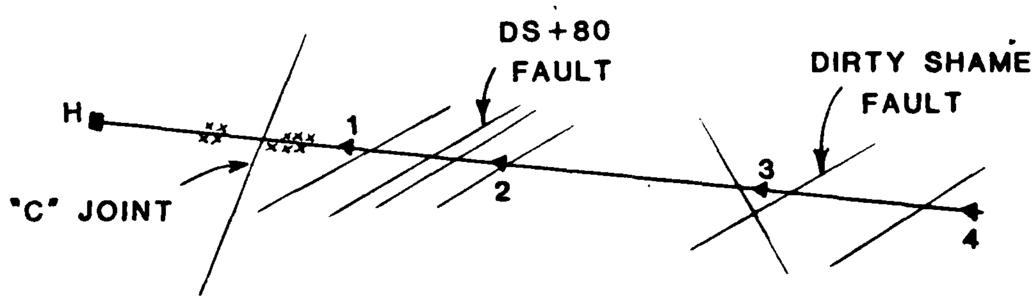

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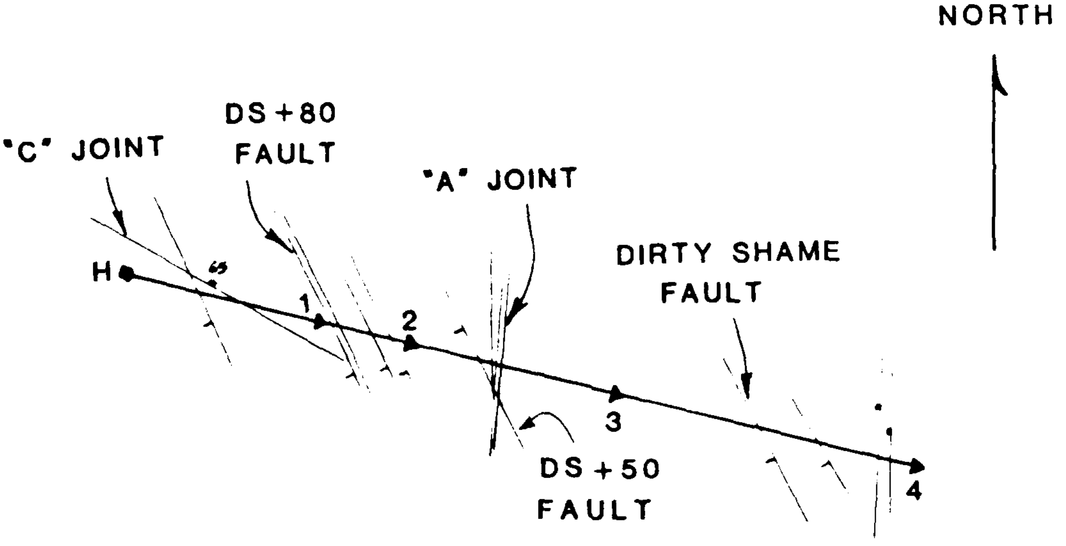

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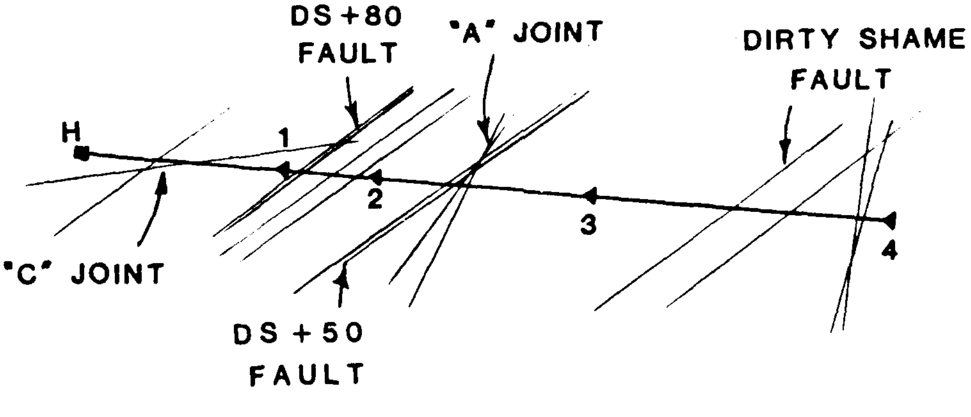

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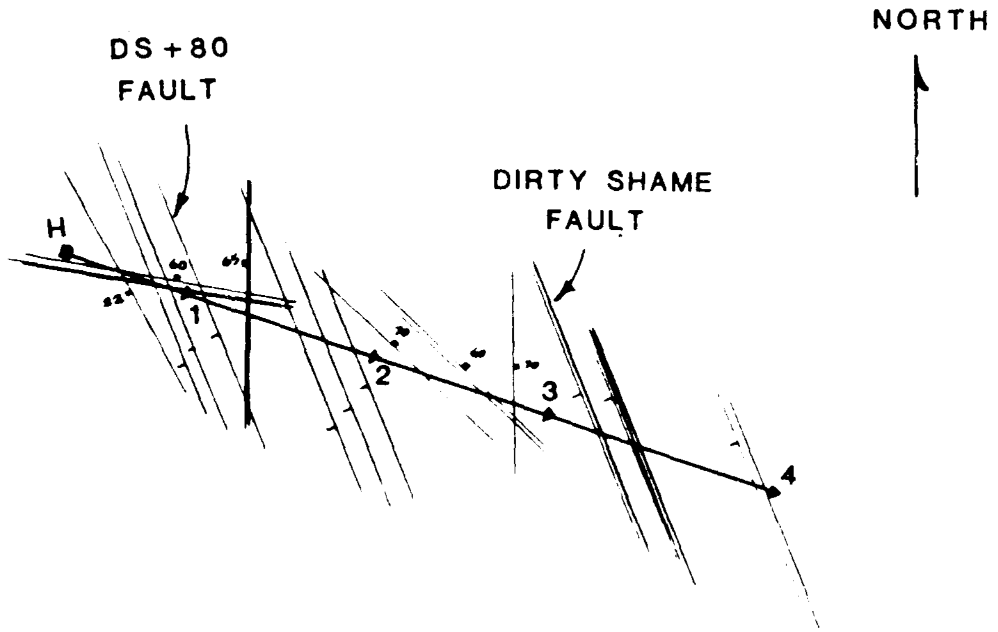

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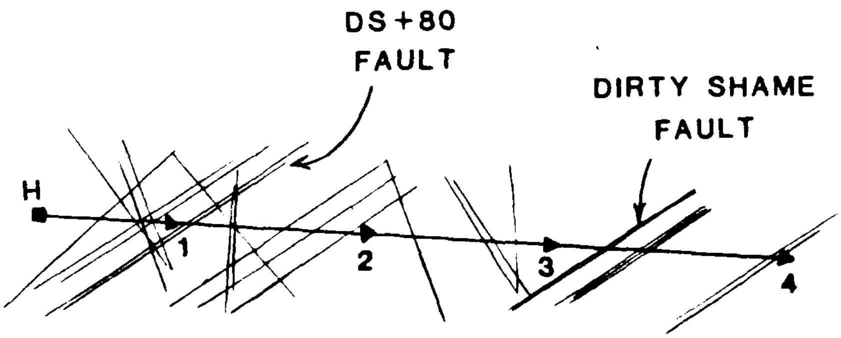

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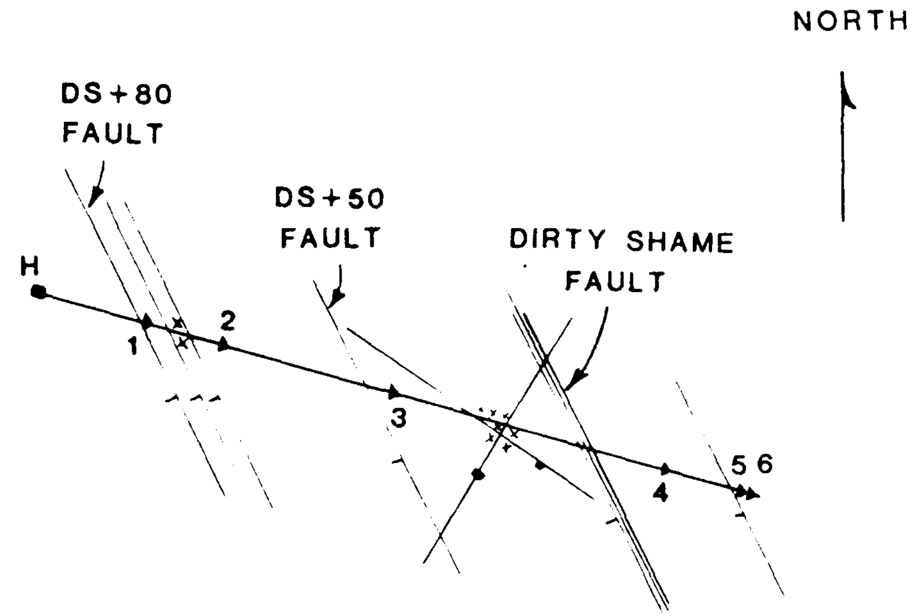

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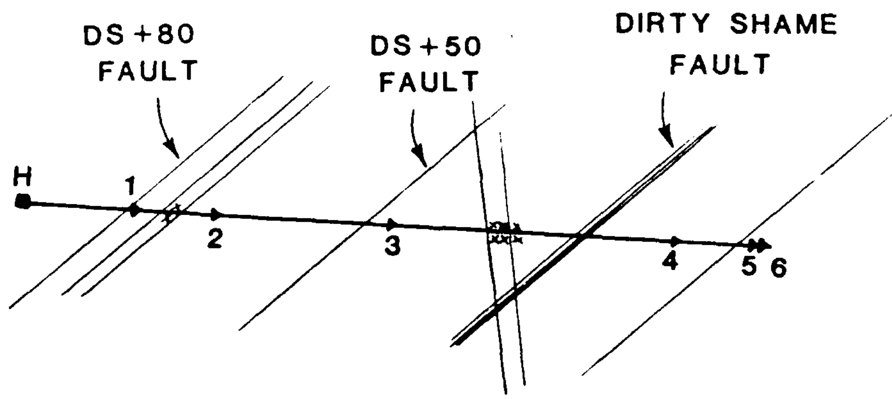

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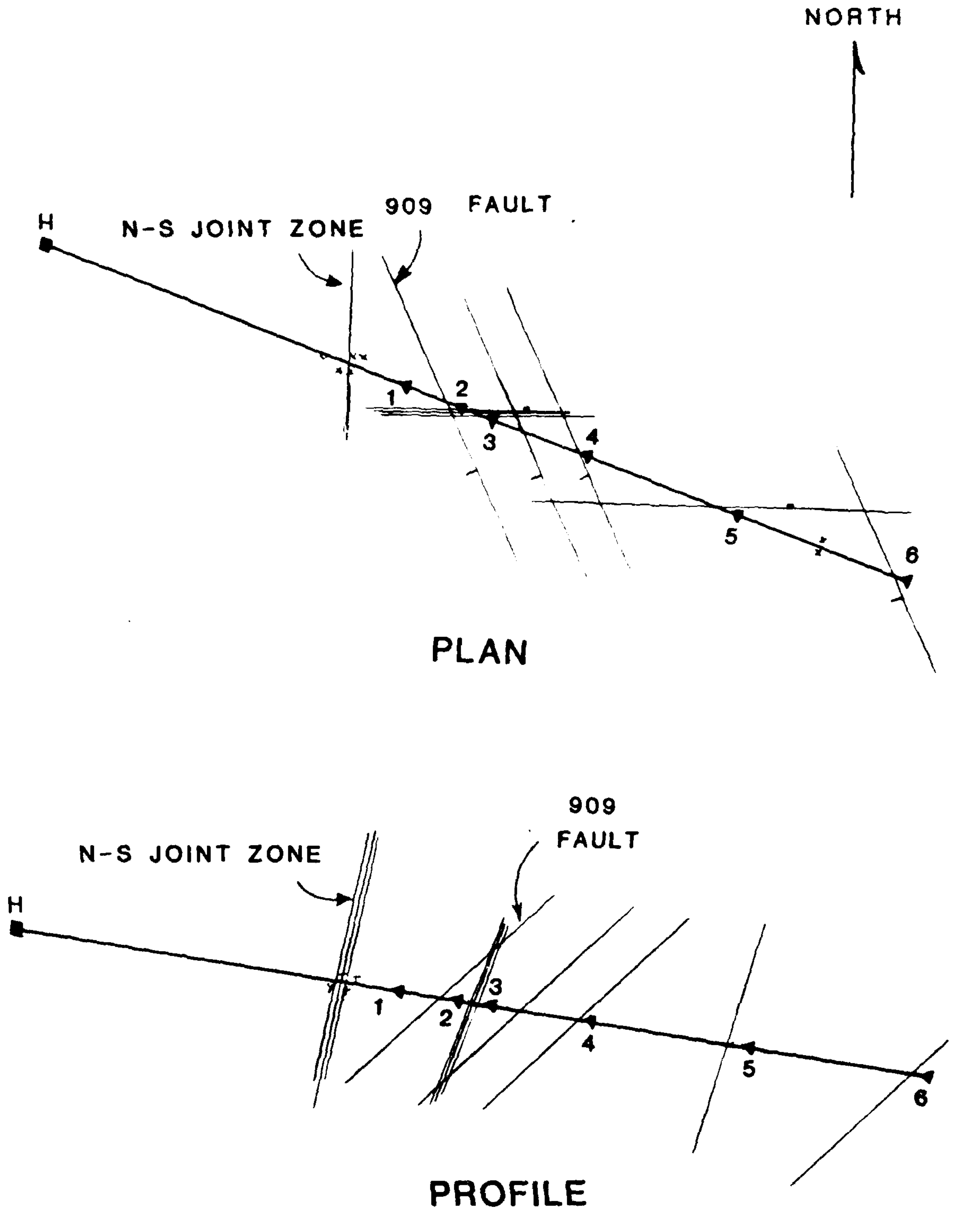
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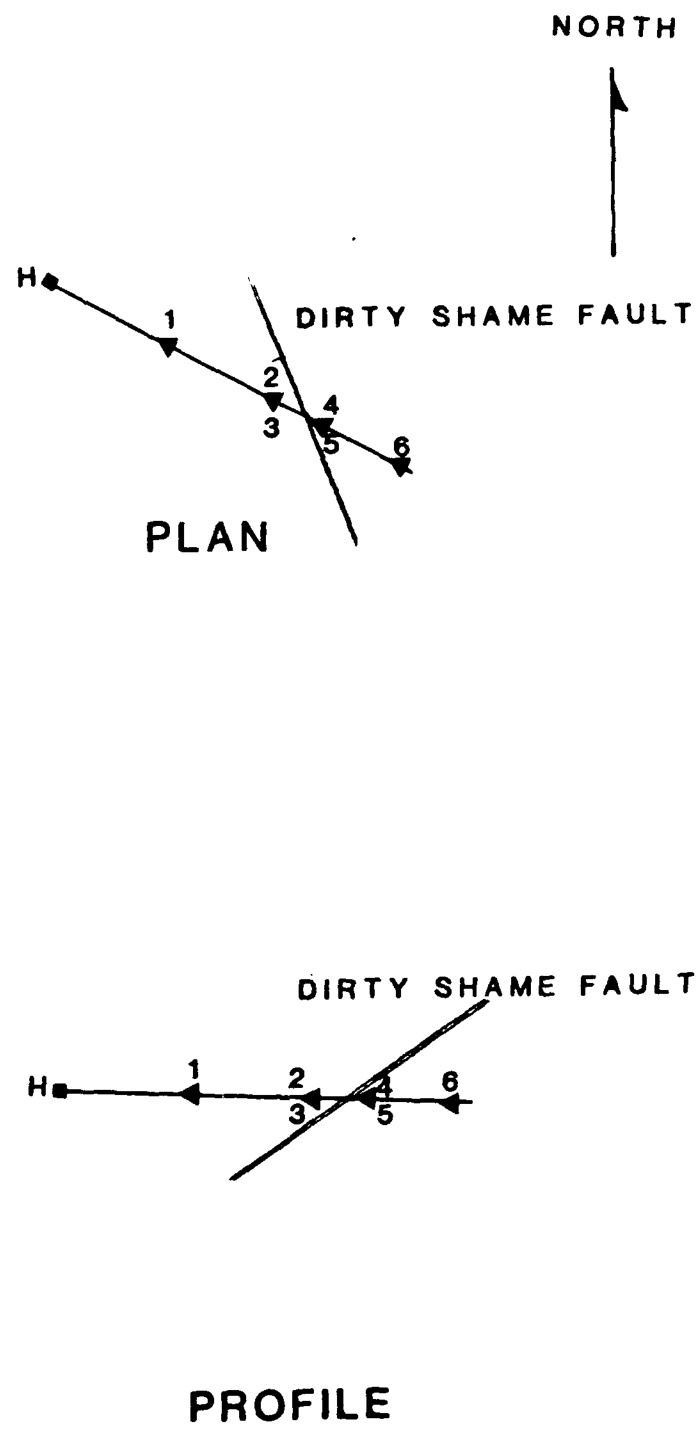
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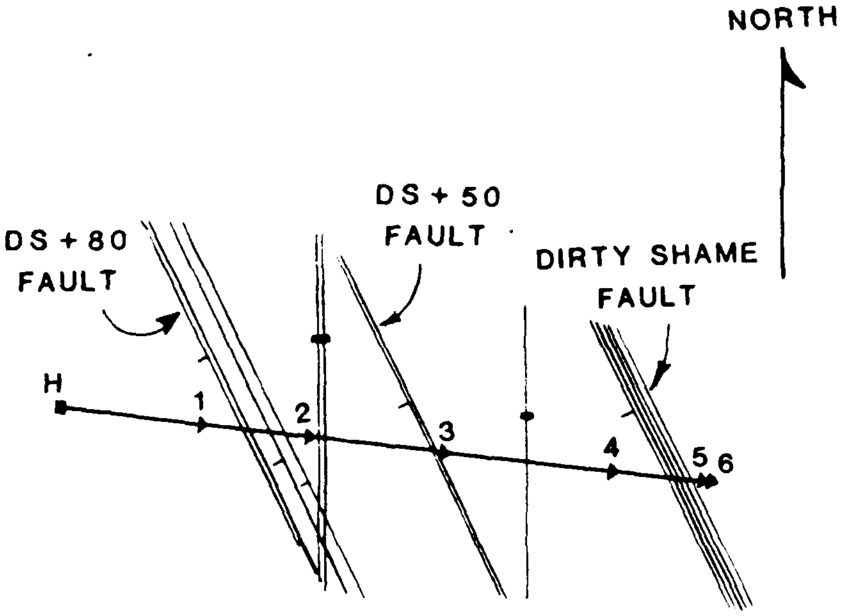

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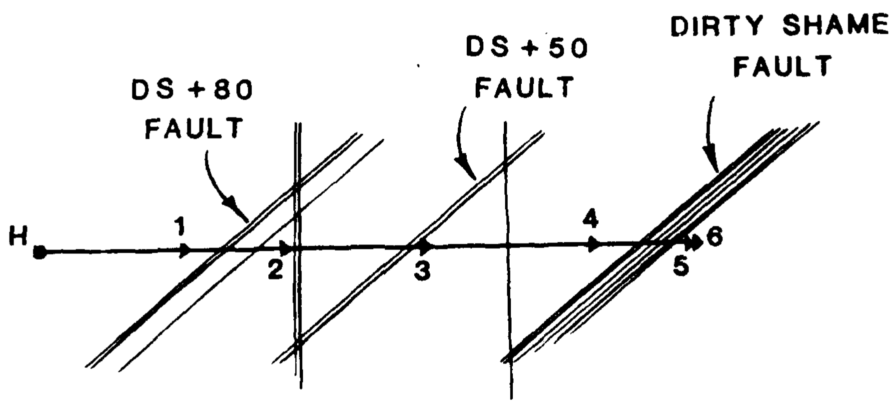

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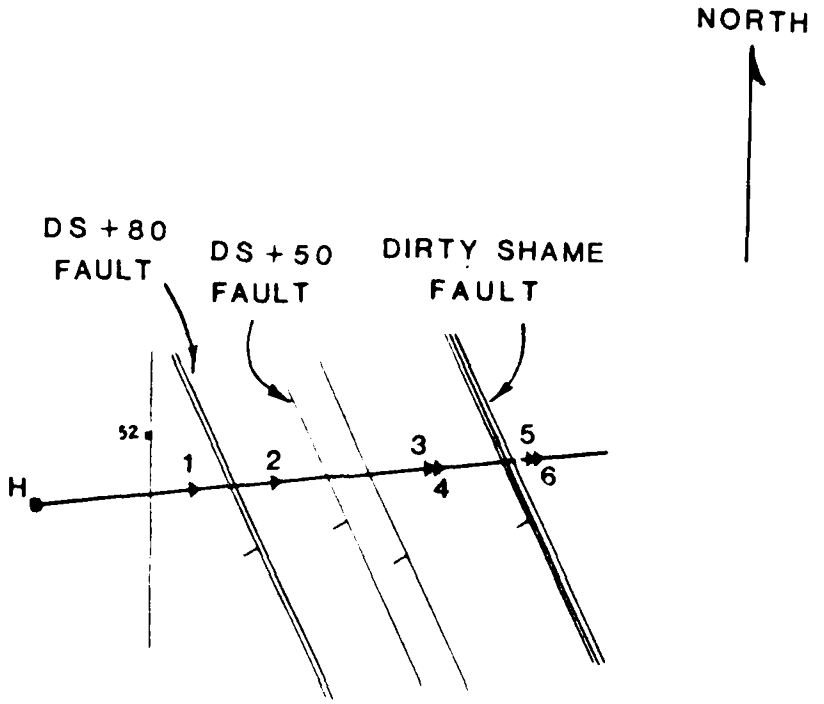

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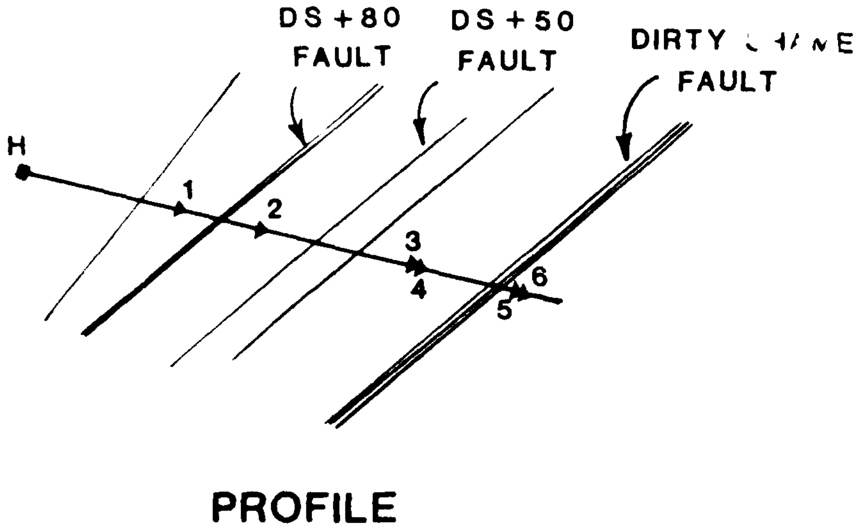

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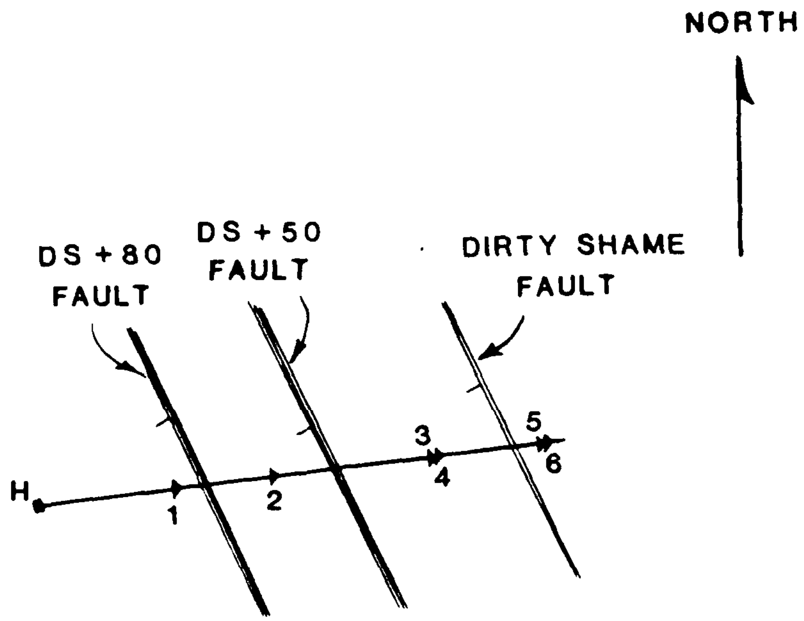

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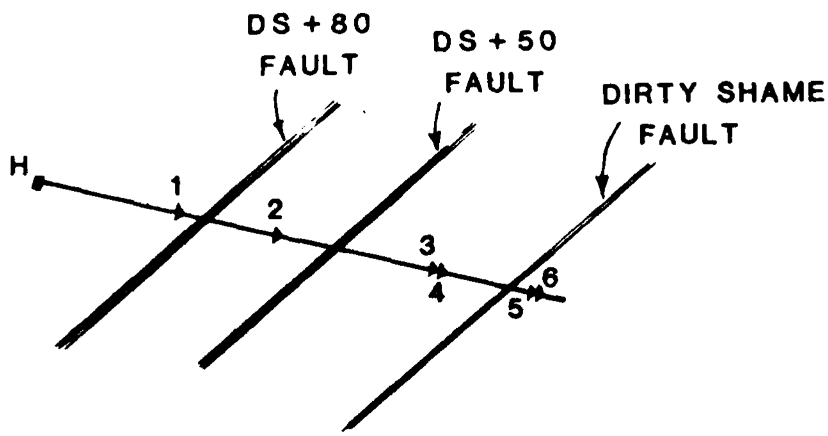

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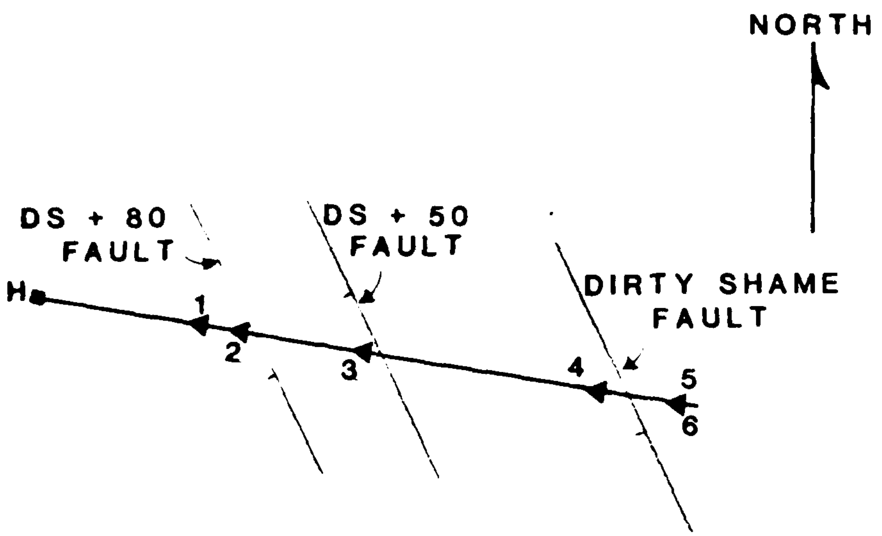

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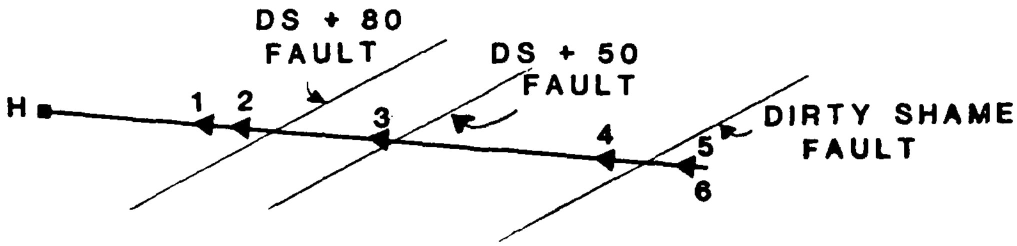

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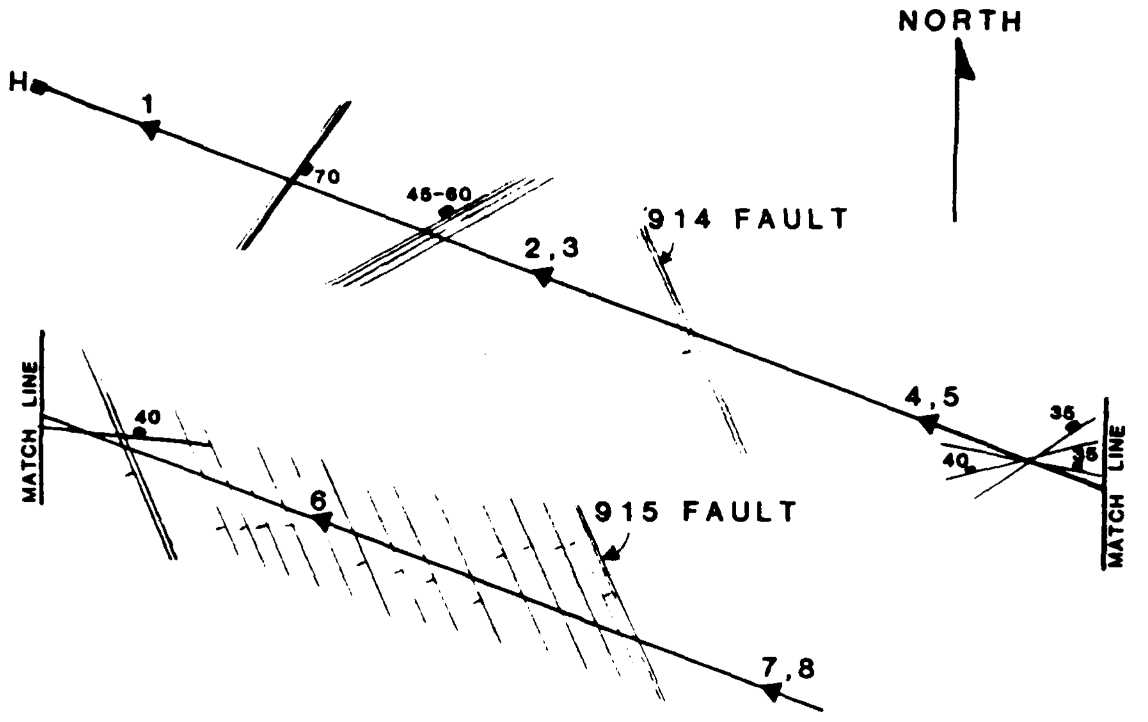

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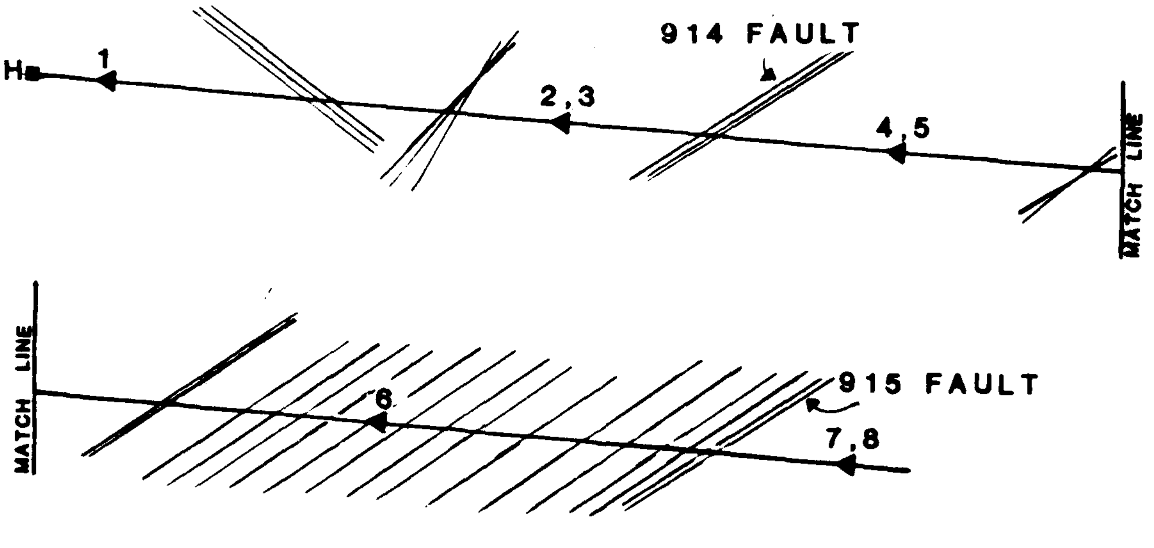

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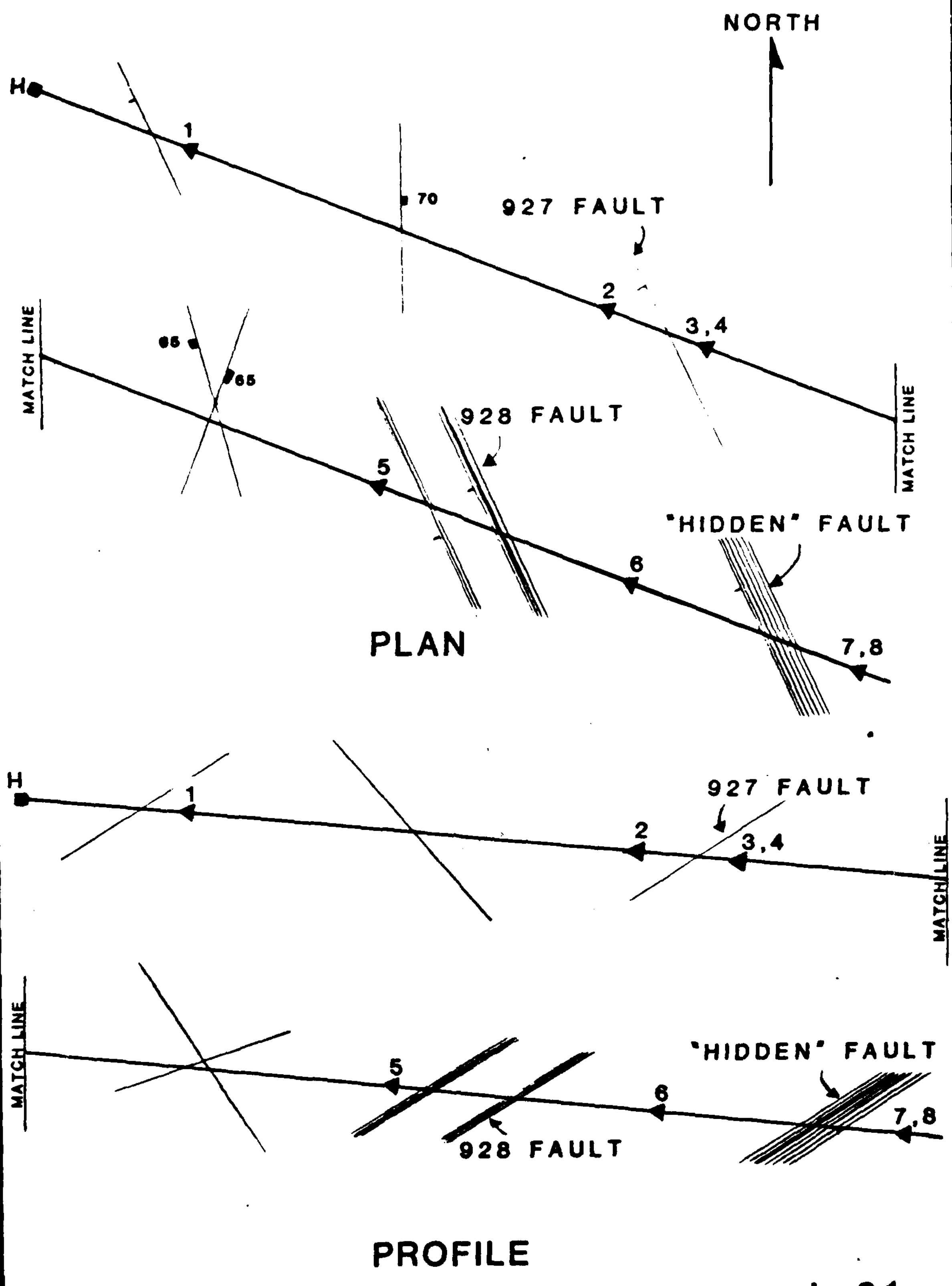
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928 FAULT
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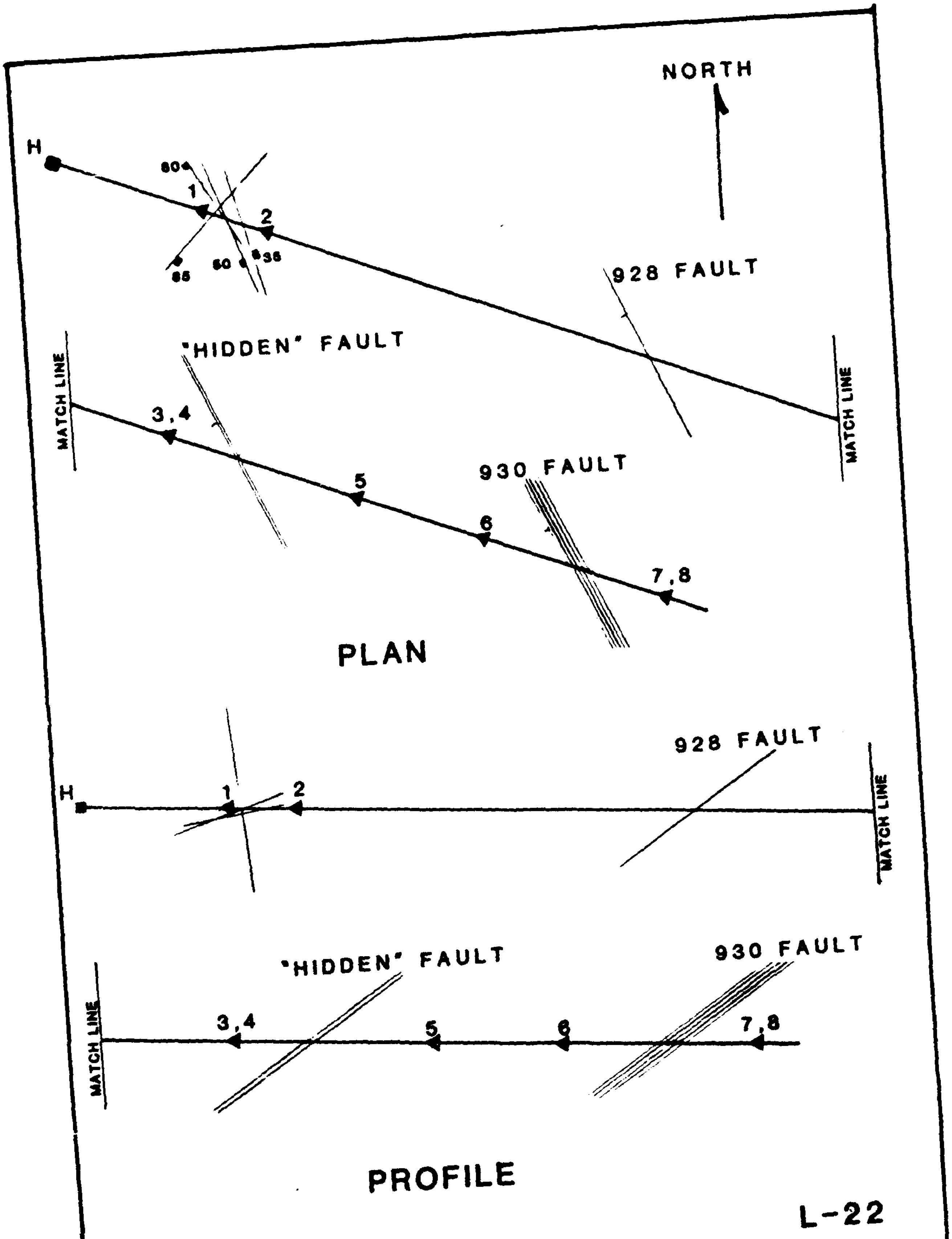
L-21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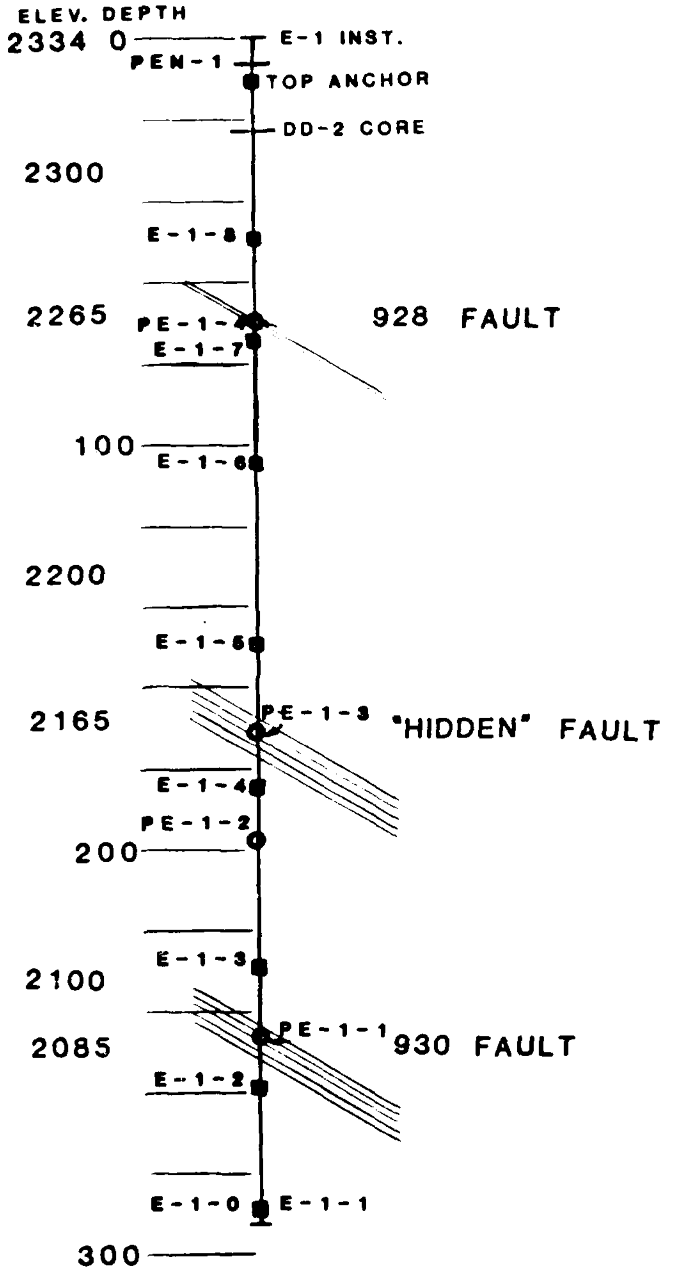

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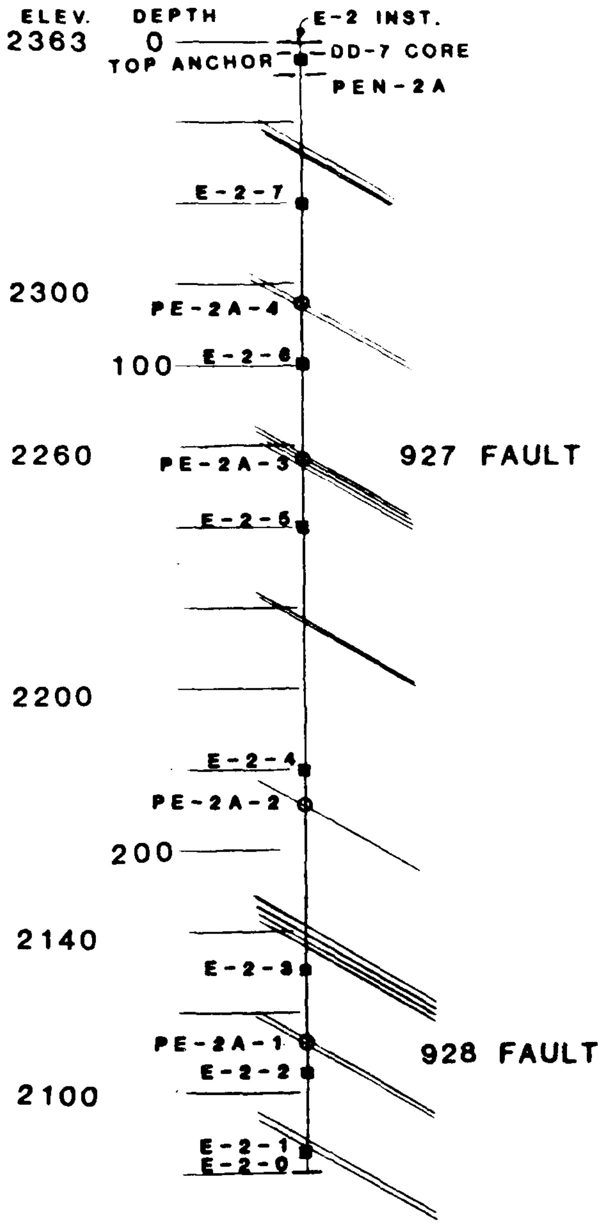

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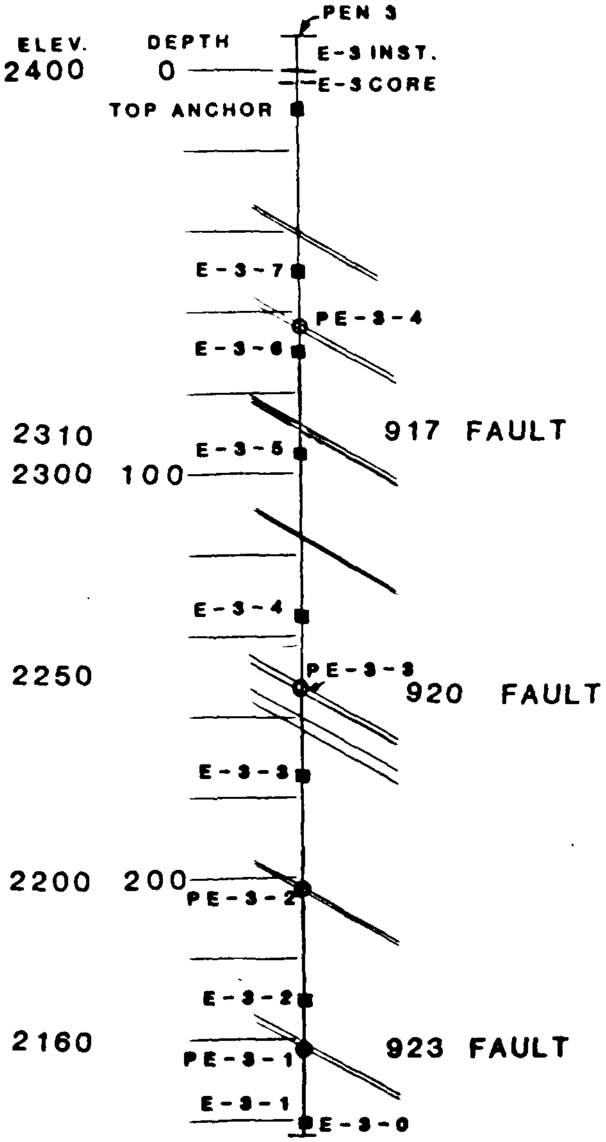

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PE-3-1 INOPERATIVE SINCE 1975.

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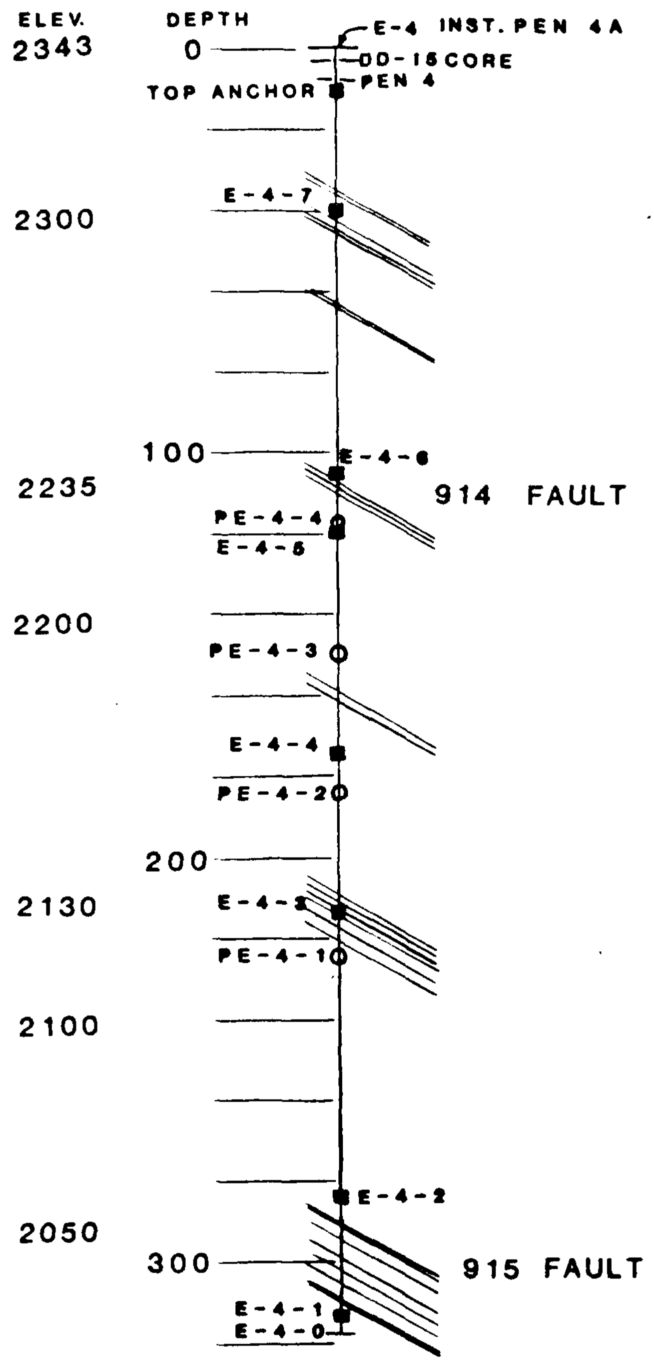

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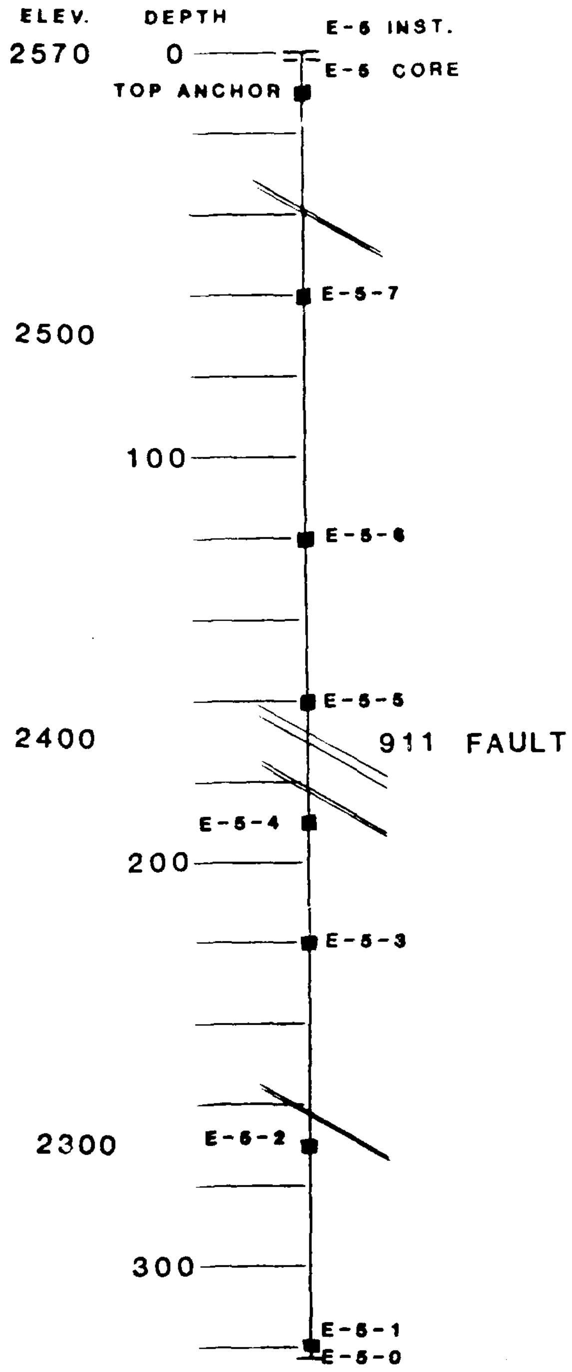
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DEPTH
E-5 INST.
2570
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E-5 CORE
TOP ANCHOR
E-5-7
2500
100
E-5-6
E-5-5
2400
911 FAULT
E-5-4
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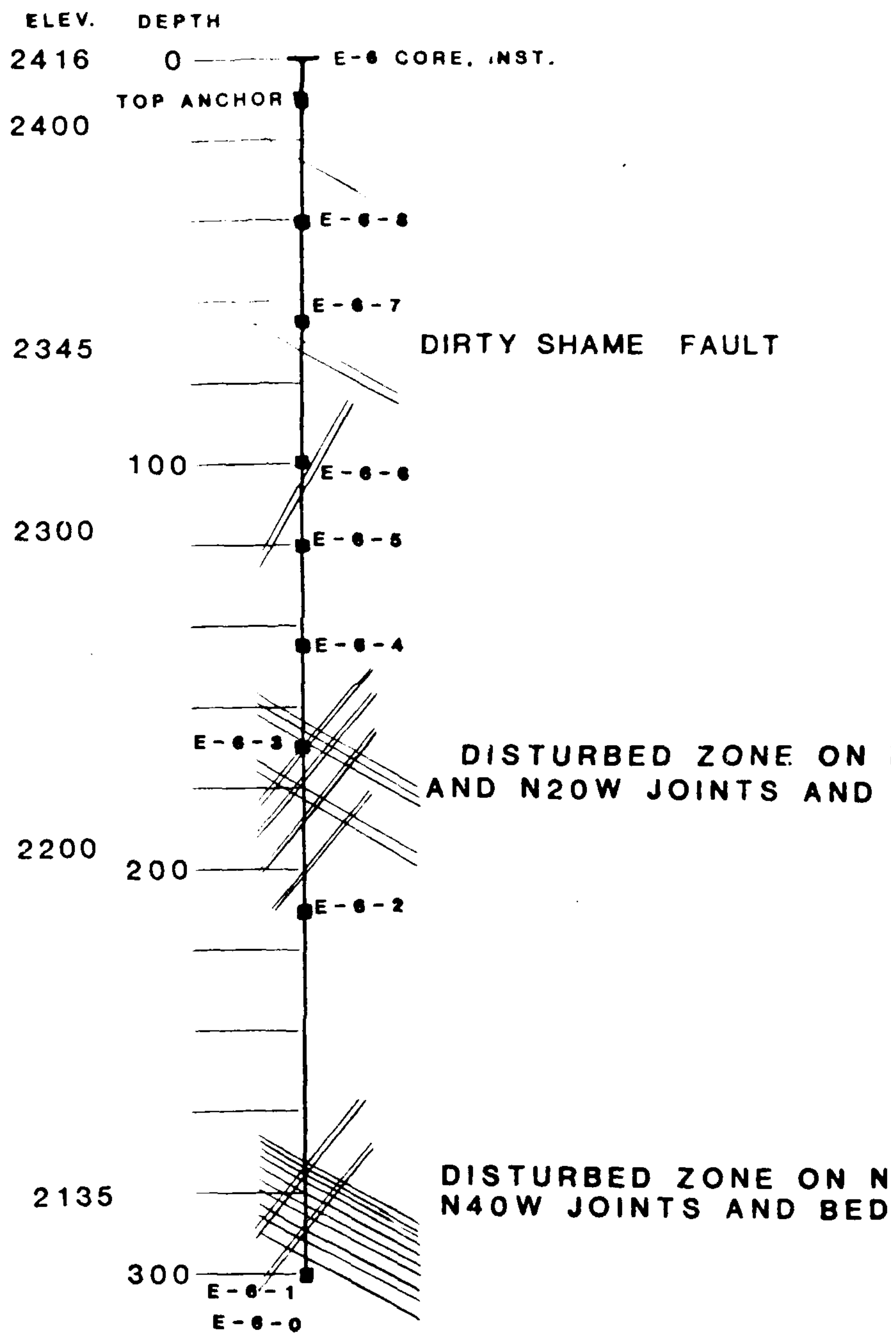
E-5-3
2300
E-5-2
300
E-5-1
E-5-0

E-5



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DEPTH
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E-6 CORE, INST.
TOP ANCHOR
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E-6-8
E-6-7
2345
DIRTY SHAME FAULT
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E-6-6
2300
E-6-5
E-6-4
E-6-3
DISTURBED ZONE ON
AND N20W JOINTS AND
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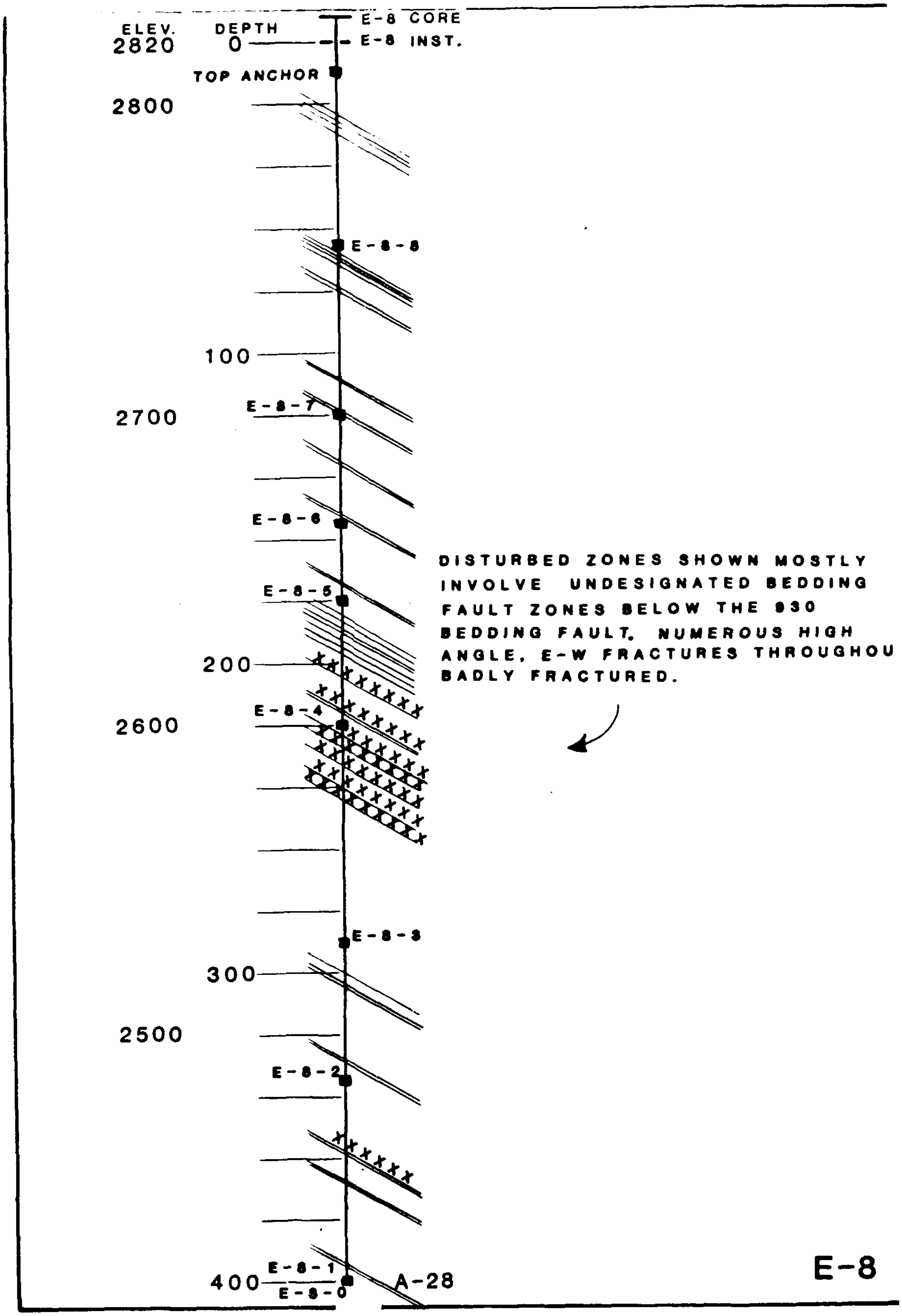

E-8 CORE
E-8 INST.
ELEV.
DEPTH
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TOP ANCHOR
2800
E-8-8
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E-8-7
2700
E-8-6
E-8-5
200
E-8-4
2600
E-8-3
300
2500
E-8-2
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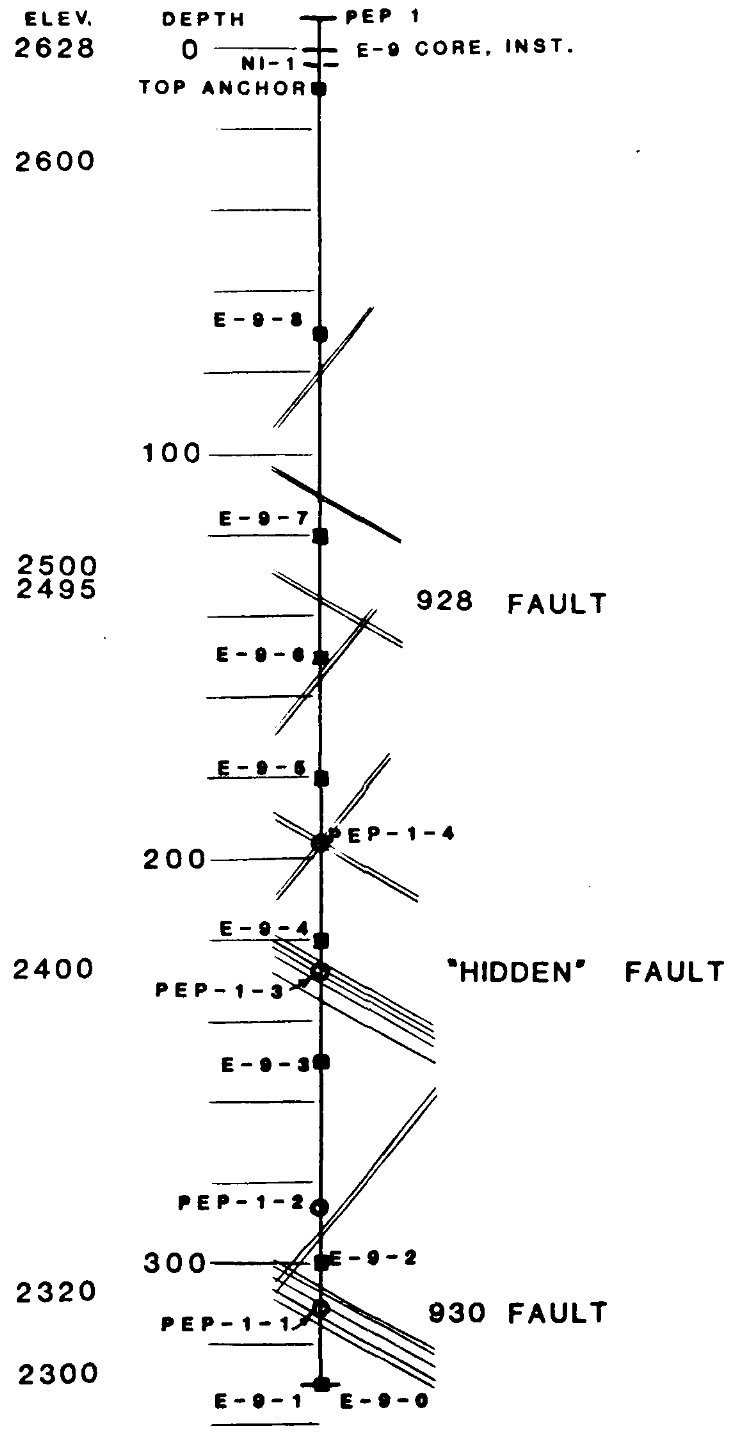
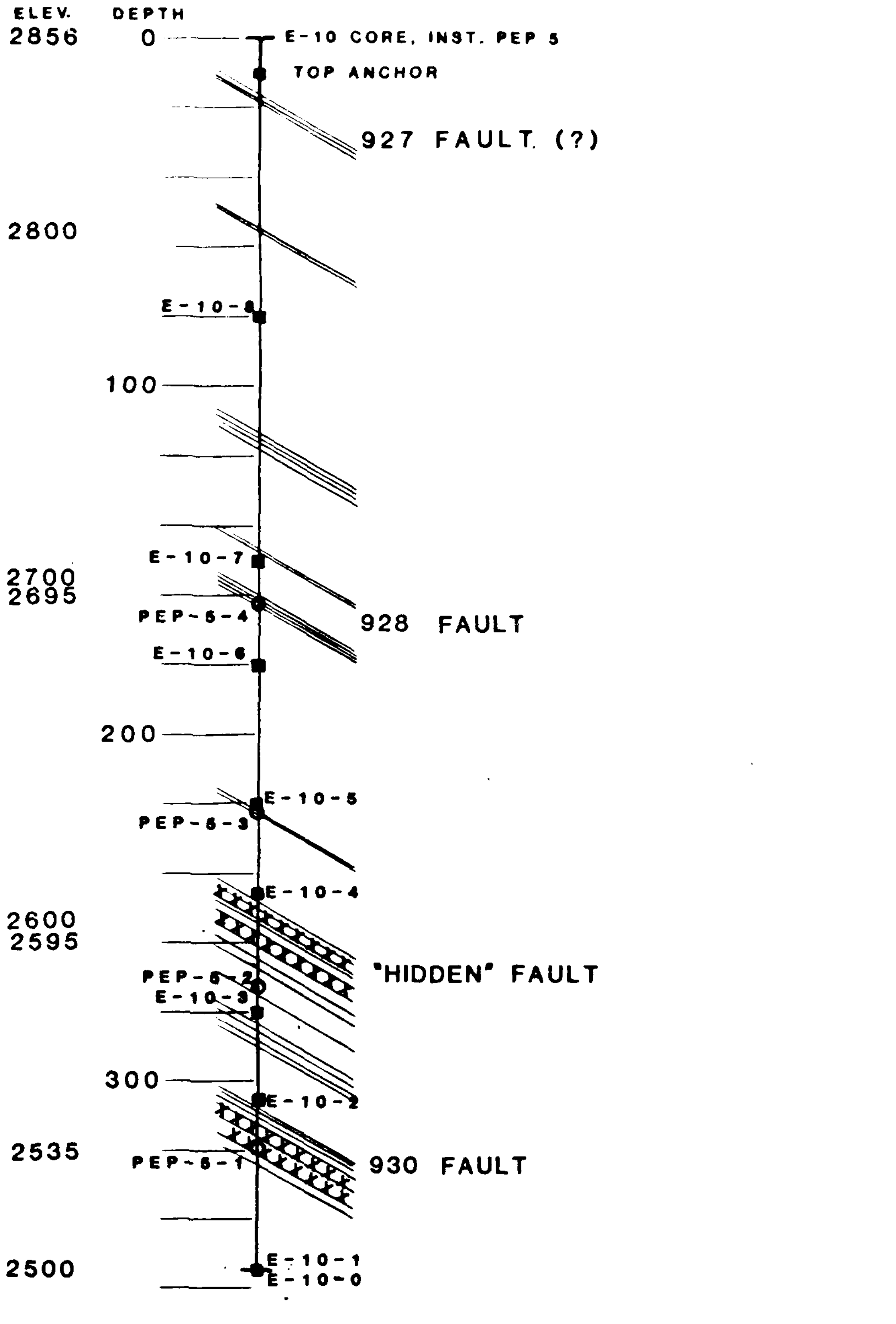
400
E-8-0
A-28
DISTURBED ZONES SHOWN MOSTLY INVOLVE UNDESIGNATED BEDDING FAULT ZONES BELOW THE 930 BEDDING FAULT. NUMEROUS HIGH ANGLE, E-W FRACTURES THROUGHOU BADLY FRACTURED.

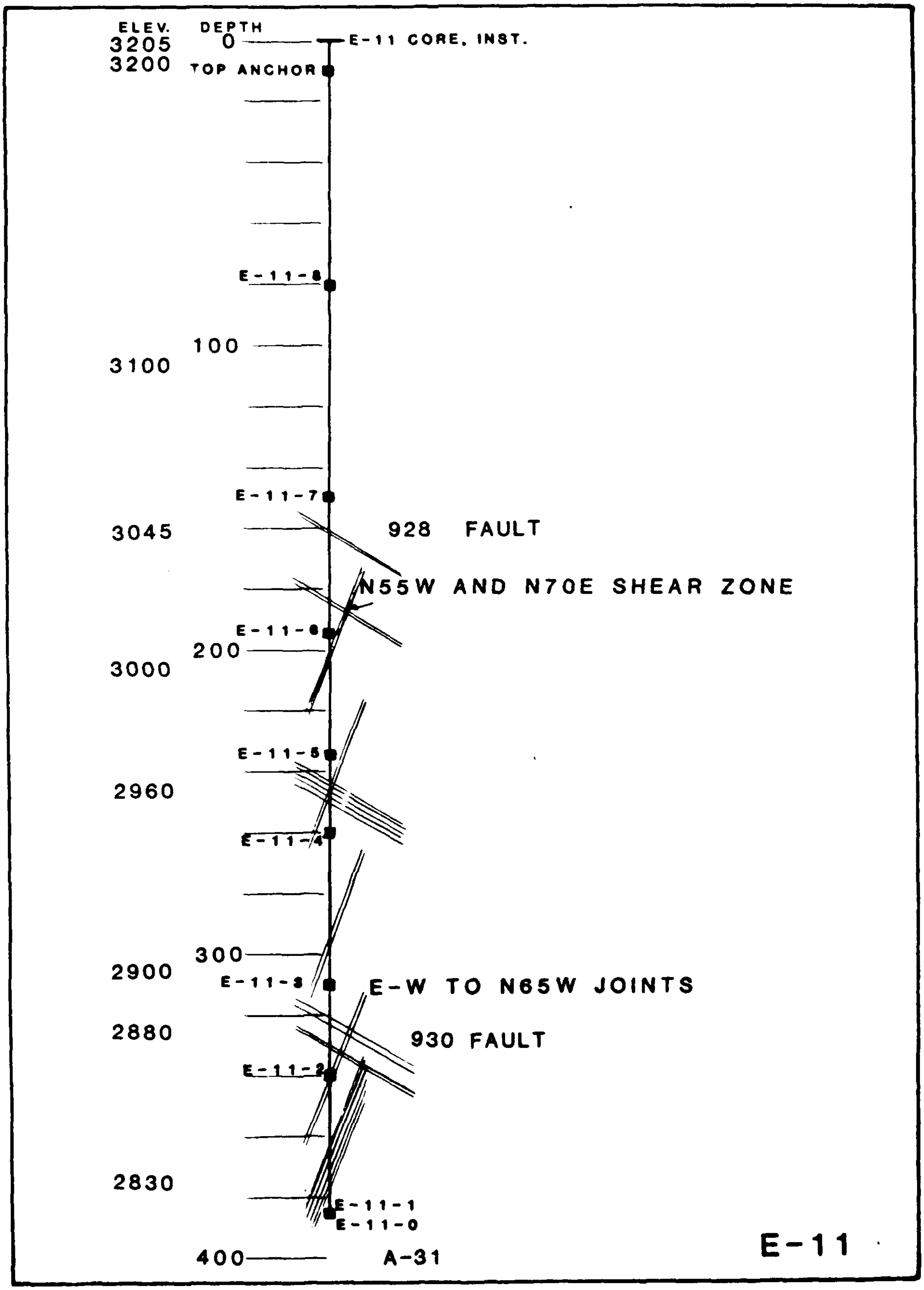
E-8

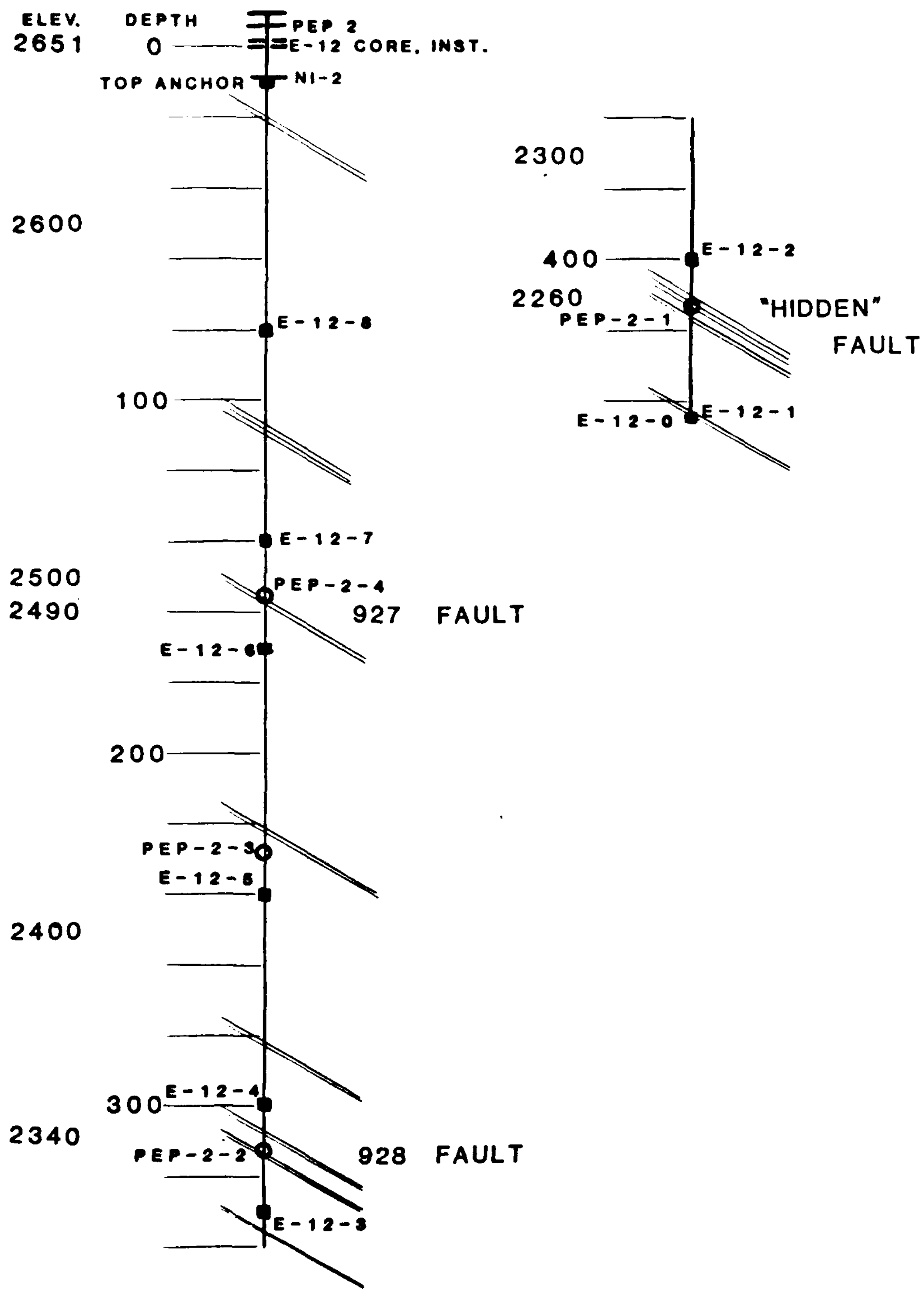


NOTE: PEP-1 SENSORS 1 AND 2 INOPERATIVE.

E-9/PEP-1/NI-1

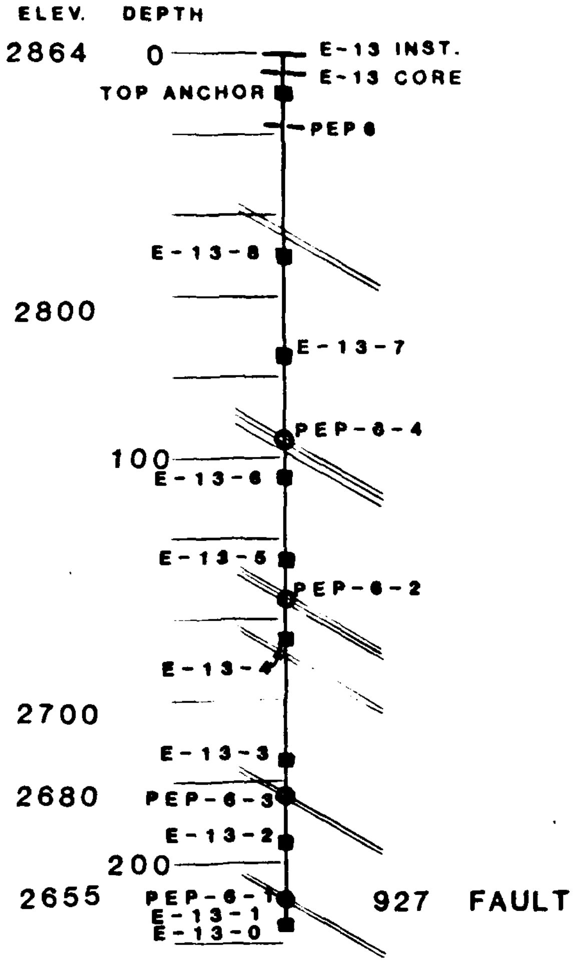

ELEV.
DEPTH
2856
0
E-10 CORE, INST. PEP 5
TOP ANCHOR
927 FAULT (?)
2800
E-10-8
100
E-10-7
2700
2695
PEP-5-4
928 FAULT
E-10-6
200
E-10-5
PEP-5-3
E-10-4
2600
2595
"HIDDEN" FAULT
PEP-5-2
E-10-3
300
E-10-2
2535
PEP-5-1
930 FAULT
2500
E-10-1
E-10-0
E-10/PEP-5


ELEV.
DEPTH
3205
0
E-11 CORE, INST.
3200
TOP ANCHOR
E-11-8
100
3100
E-11-7
3045
928 FAULT
N55W AND N70E SHEAR ZONE
E-11-6
200
3000
E-11-5
2960
E-11-4
300
2900
E-11-3
E-W TO N65W JOINTS
2880
930 FAULT
E-11-2
2830
E-11-1
E-11-0
400
A-31
E-11



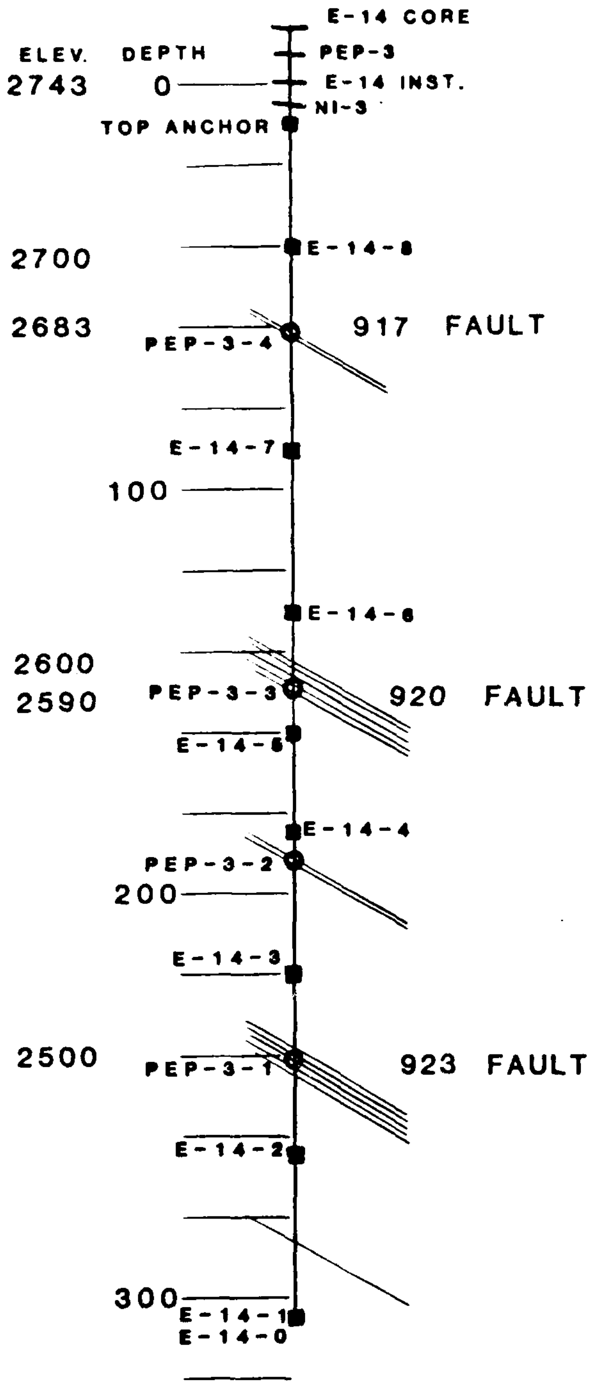
ELEV.
DEPTH
2651
0
PEP 2
E-12 CORE, INST.
TOP ANCHOR
NI-2
2600
E-12-8
100
E-12-7
2500
2490
PEP-2-4
927 FAULT
E-12-6
200
PEP-2-3
E-12-5
2400
300
E-12-4
2340
PEP-2-2
928 FAULT
E-12-3
2300
400
E-12-2
2260
PEP-2-1
"HIDDEN" FAULT
E-12-0
E-12-1

E-12/PEP-2/NI-2

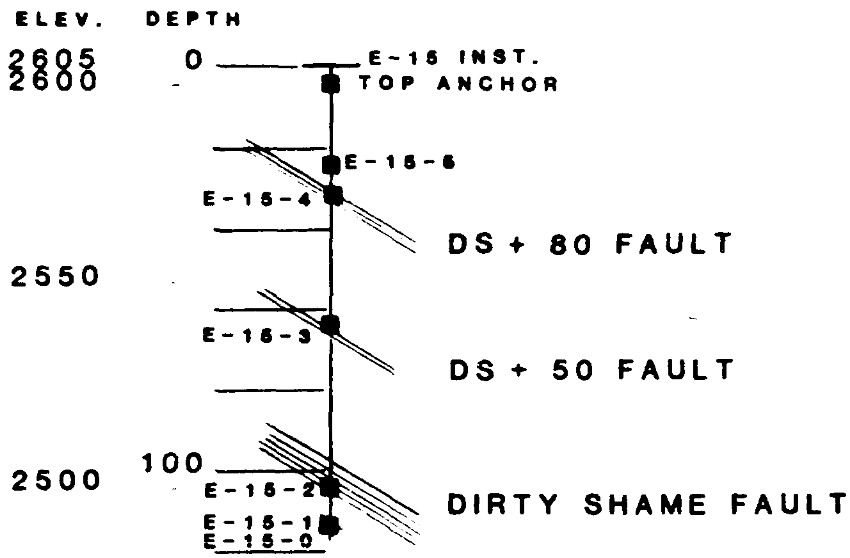


ELEV. DEPTH
2864 0
E-13 INST.
E-13 CORE
TOP ANCHOR
PEP 6
E-13-8
2800
E-13-7
PEP-6-4
100
E-13-6
E-13-5
PEP-6-2
E-13-4
2700
E-13-3
2680
PEP-6-3
E-13-2
200
2655
PEP-6-1
E-13-1
E-13-0
927 FAULT

E-13/PEP-6

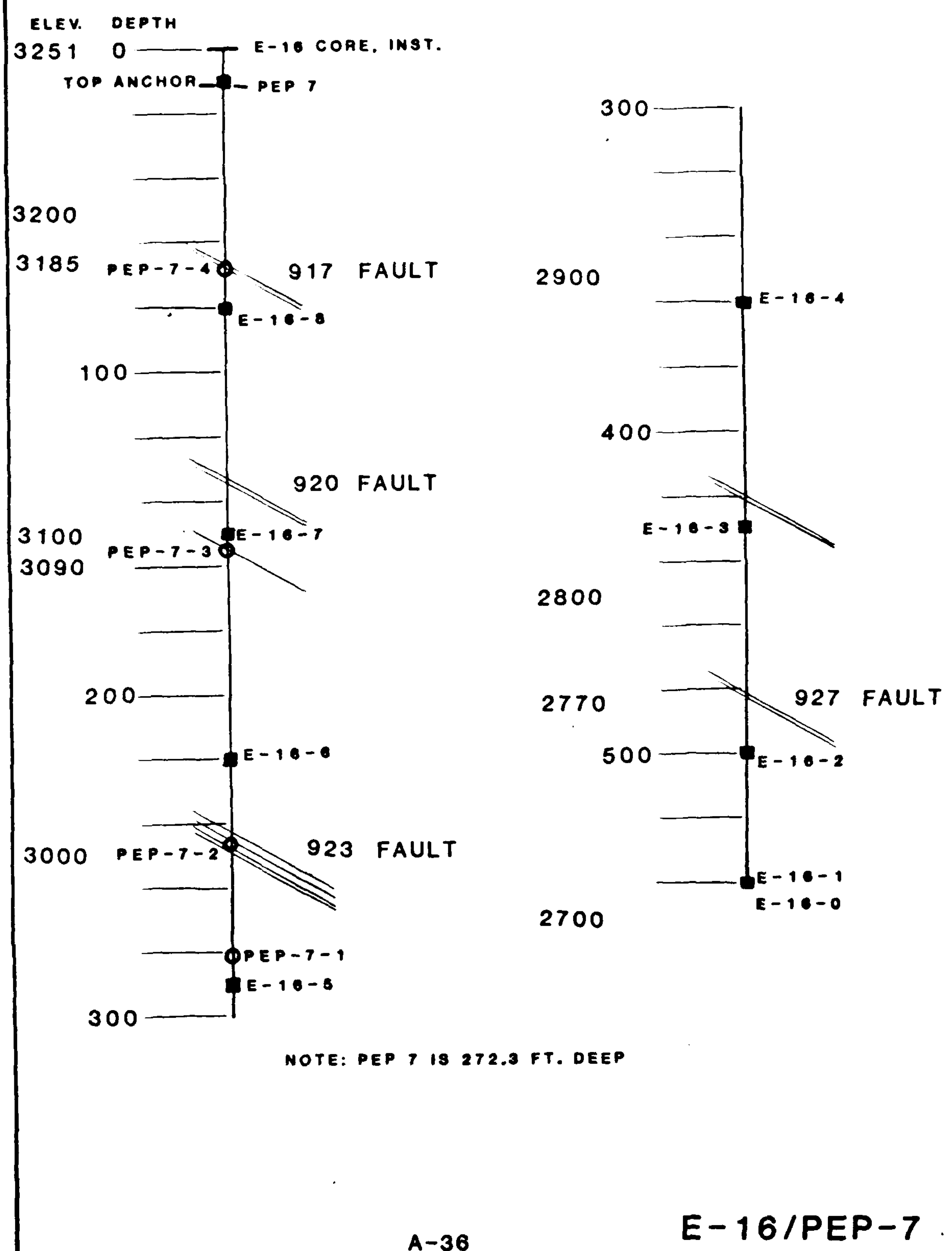

E-14 CORE
PEP-3
ELEV.
DEPTH
2743
0
E-14 INST.
NI-3
TOP ANCHOR
2700
E-14-8
2683
PEP-3-4
917
FAULT
E-14-7
100
E-14-6
2600
2590
PEP-3-3
920
FAULT
E-14-5
E-14-4
PEP-3-2
200
E-14-3
2500
PEP-3-1
923
FAULT
E-14-2
300
E-14-1
E-14-0

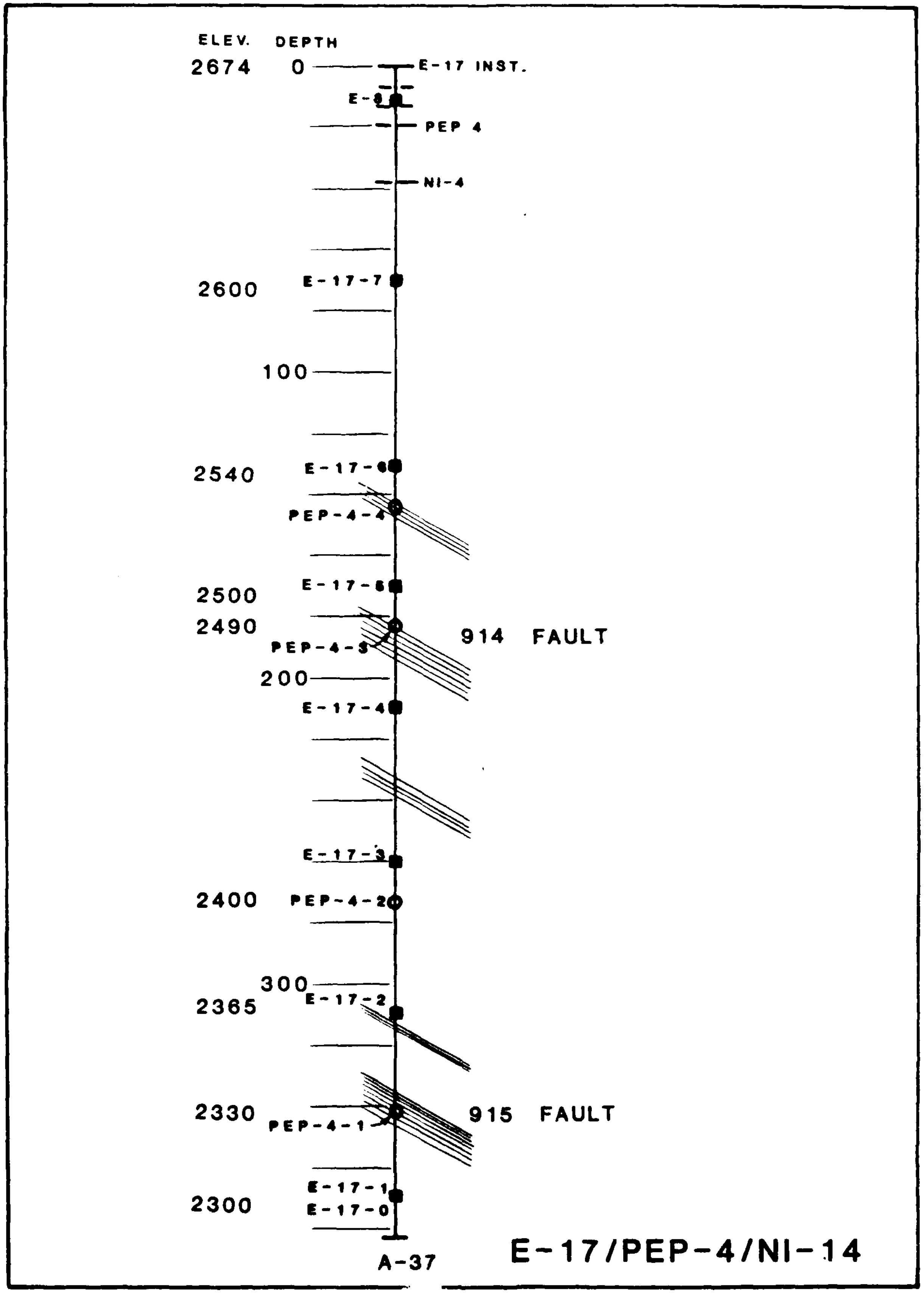
E-14/PEP-3/NI-3

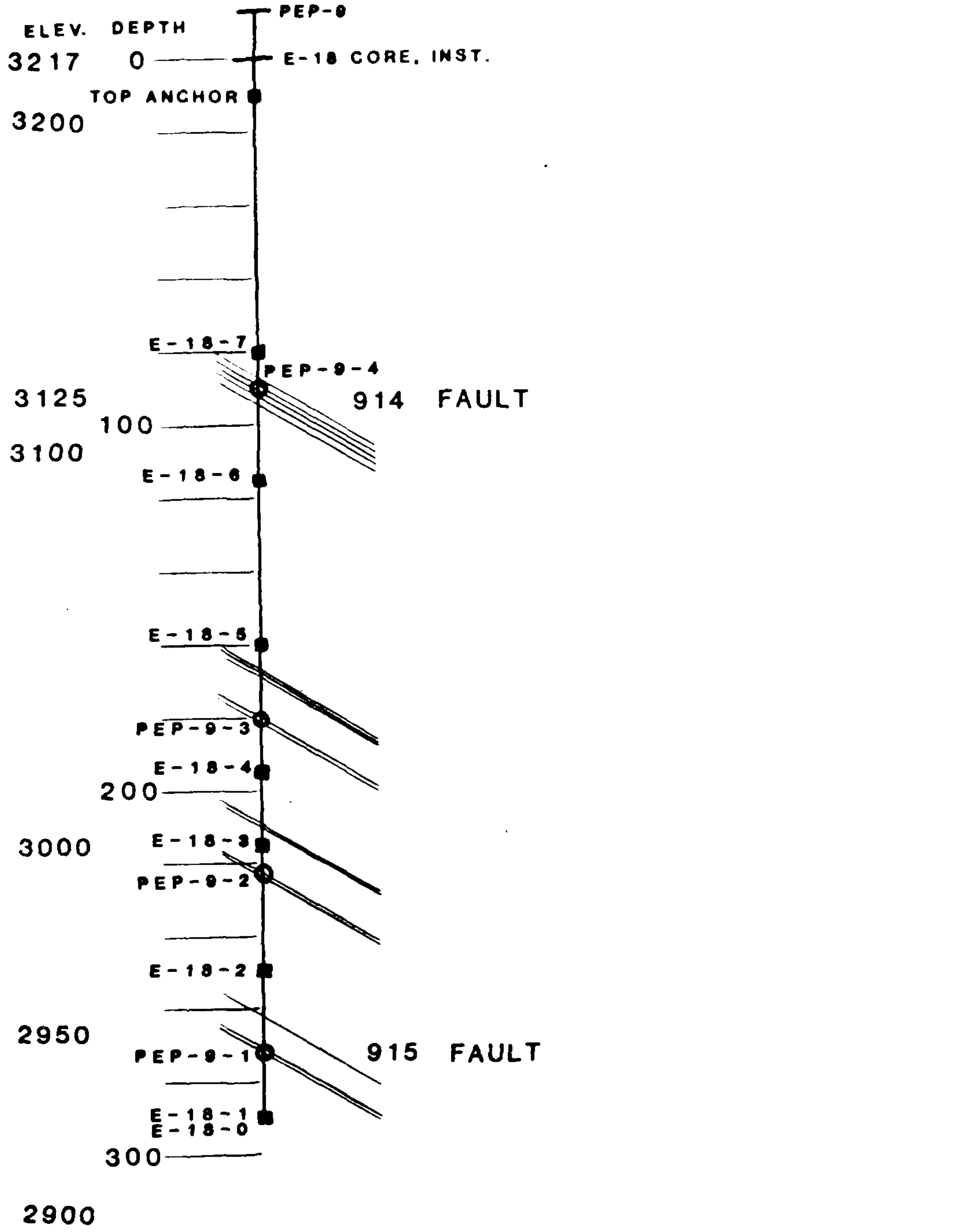


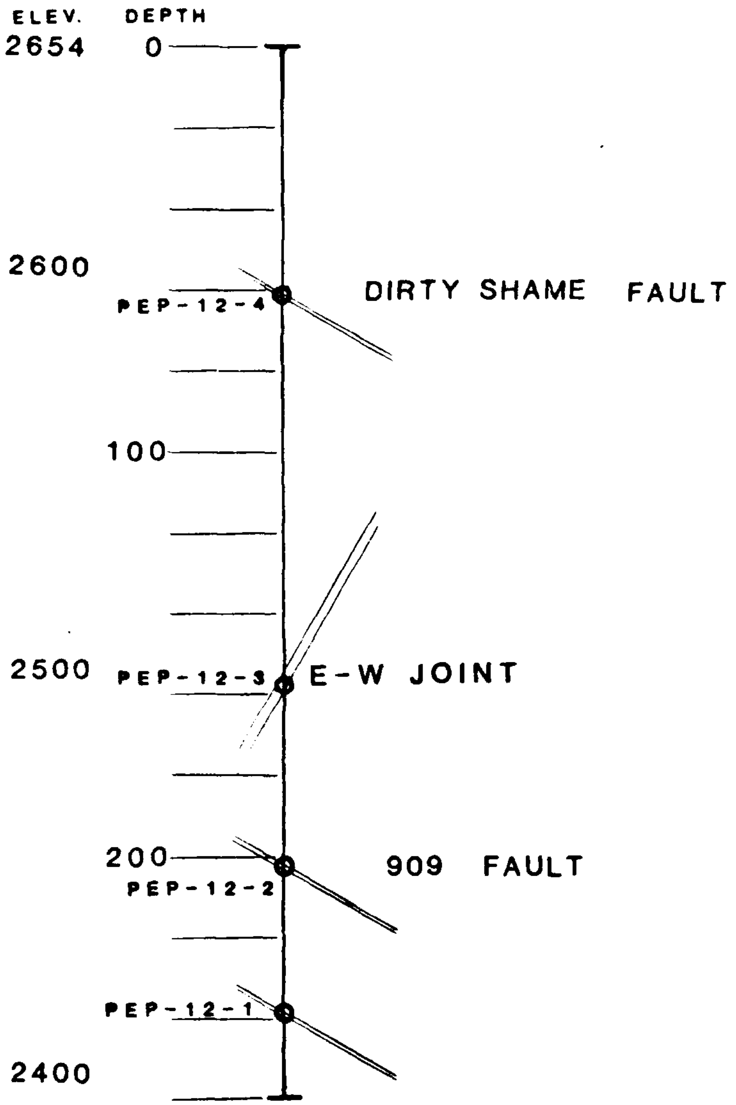
ELEV.
DEPTH
2605
2600
0
E-15 INST.
TOP ANCHOR
E-15-5
E-15-4
DS + 80 FAULT
2550
E-15-3
DS + 50 FAULT
100
2500
E-15-2
E-15-1
E-15-0
DIRTY SHAME FAULT

E-15


ELEV. DEPTH
3251 0 E-16 CORE, INST.
TOP ANCHOR PEP 7
3200
3185 PEP-7-4 917 FAULT
E-16-8
100
920 FAULT
3100 E-16-7
PEP-7-3
3090
200
E-16-6
3000 PEP-7-2 923 FAULT
PEP-7-1
E-16-5
300
300
2900
E-16-4
400
E-16-3
2800
2770
927 FAULT
500
E-16-2
E-16-1
E-16-0
2700
NOTE: PEP 7 IS 272.3 FT. DEEP
E-16/PEP-7

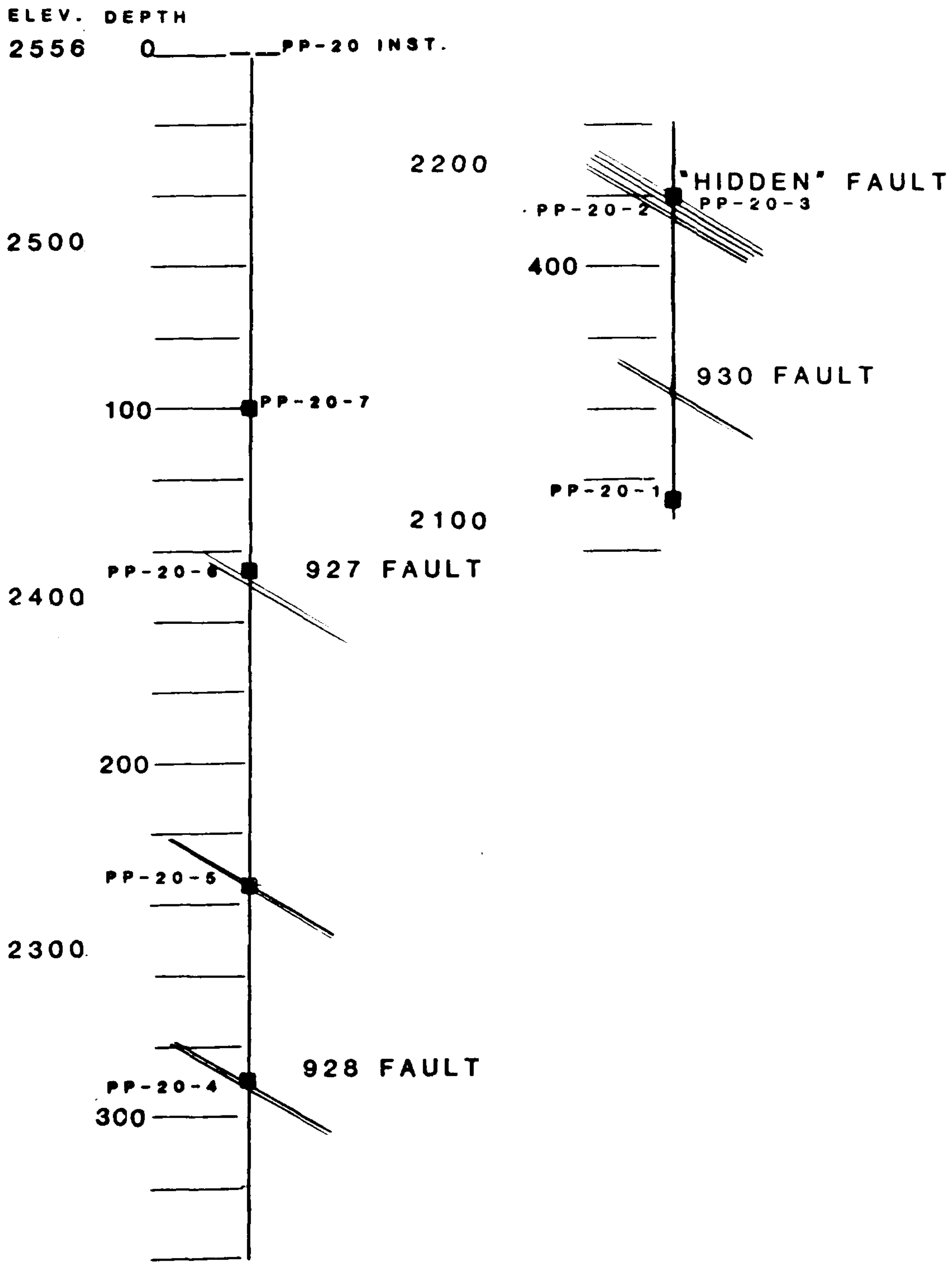

ELEV.
DEPTH
2674
0
E-17 INST.
PEP 4
NI-4
2600
E-17-7
100
2540
E-17-6
PEP-4-4
2500
E-17-5
2490
PEP-4-3
914 FAULT
200
E-17-4
E-17-3
2400
PEP-4-2
300
2365
E-17-2
2330
PEP-4-1
915 FAULT
E-17-1
2300
E-17-0
A-37
E-17/PEP-4/NI-14


PEP-9
ELEV. DEPTH
3217 0
E-18 CORE, INST.
TOP ANCHOR
3200
E-18-7
PEP-9-4
3125
914 FAULT
100
3100
E-18-6
E-18-5
PEP-9-3
E-18-4
200
3000
E-18-3
PEP-9-2
E-18-2
2950
PEP-9-1
915 FAULT
E-18-1
E-18-0
300
2900
E-18/PEP-9

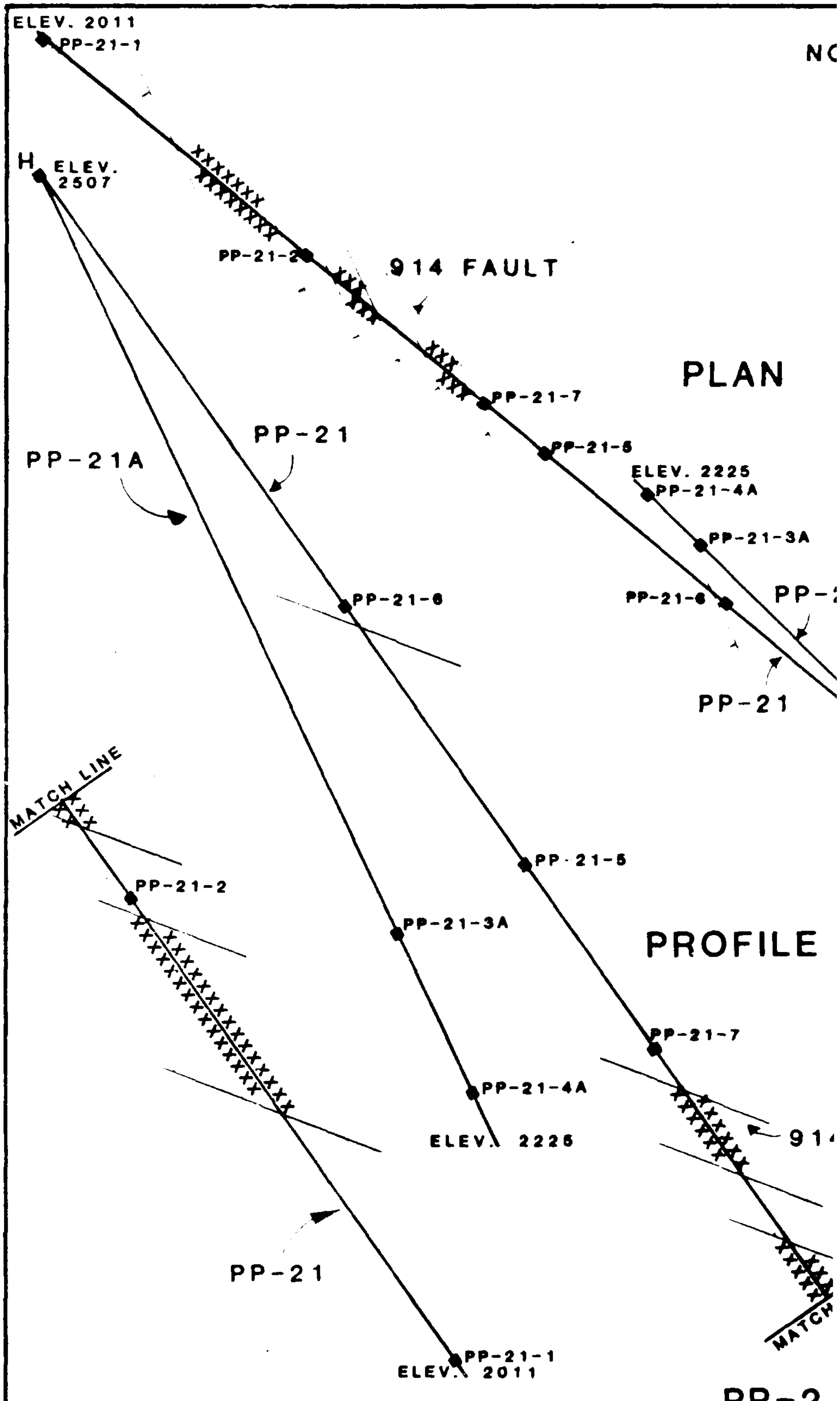


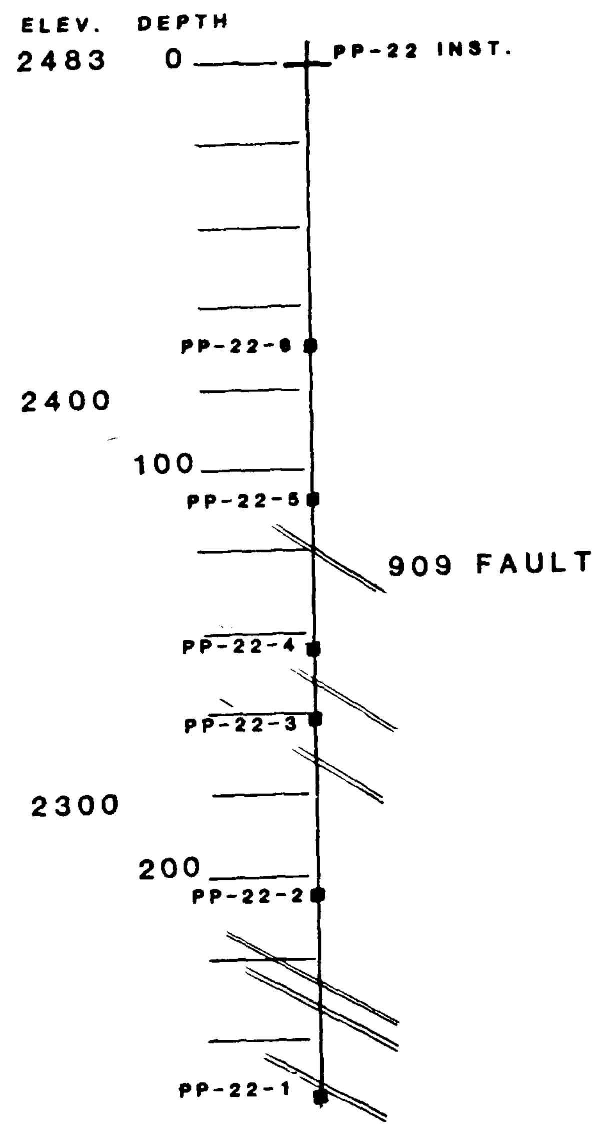
ELEV.
DEPTH
2654
0
2600
PEP-12-4
DIRTY SHAME FAULT
100
2500
PEP-12-3
E-W JOINT
200
PEP-12-2
909 FAULT
PEP-12-1
2400

PEP-12

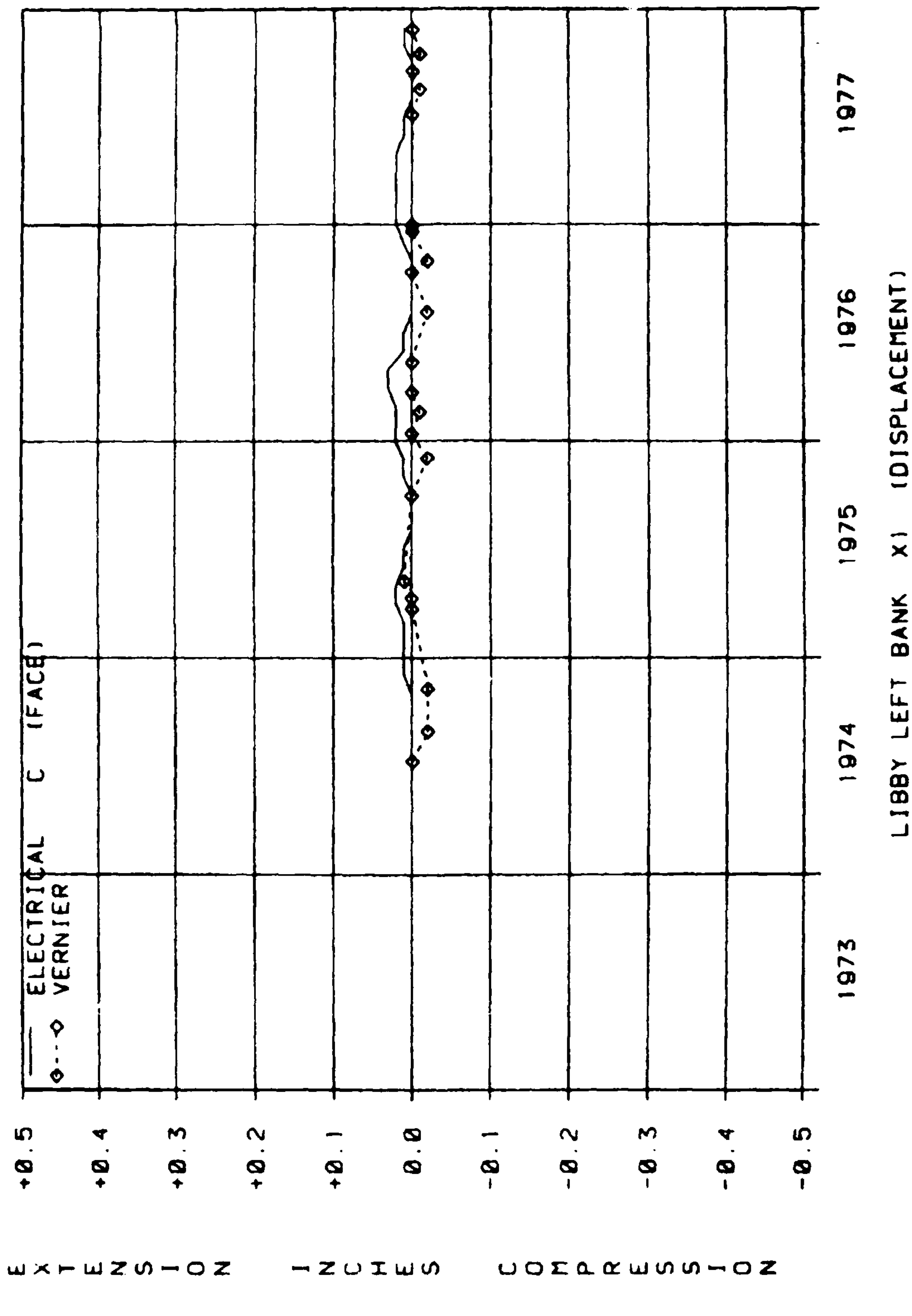

ELEV. DEPTH
2556 0
PP-20 INST.
2500
100
PP-20-7
2400
PP-20-6
927 FAULT
200
PP-20-5
2300
928 FAULT
PP-20-4
300
2200
"HIDDEN" FAULT
PP-20-2
PP-20-3
400
930 FAULT
PP-20-1
2100

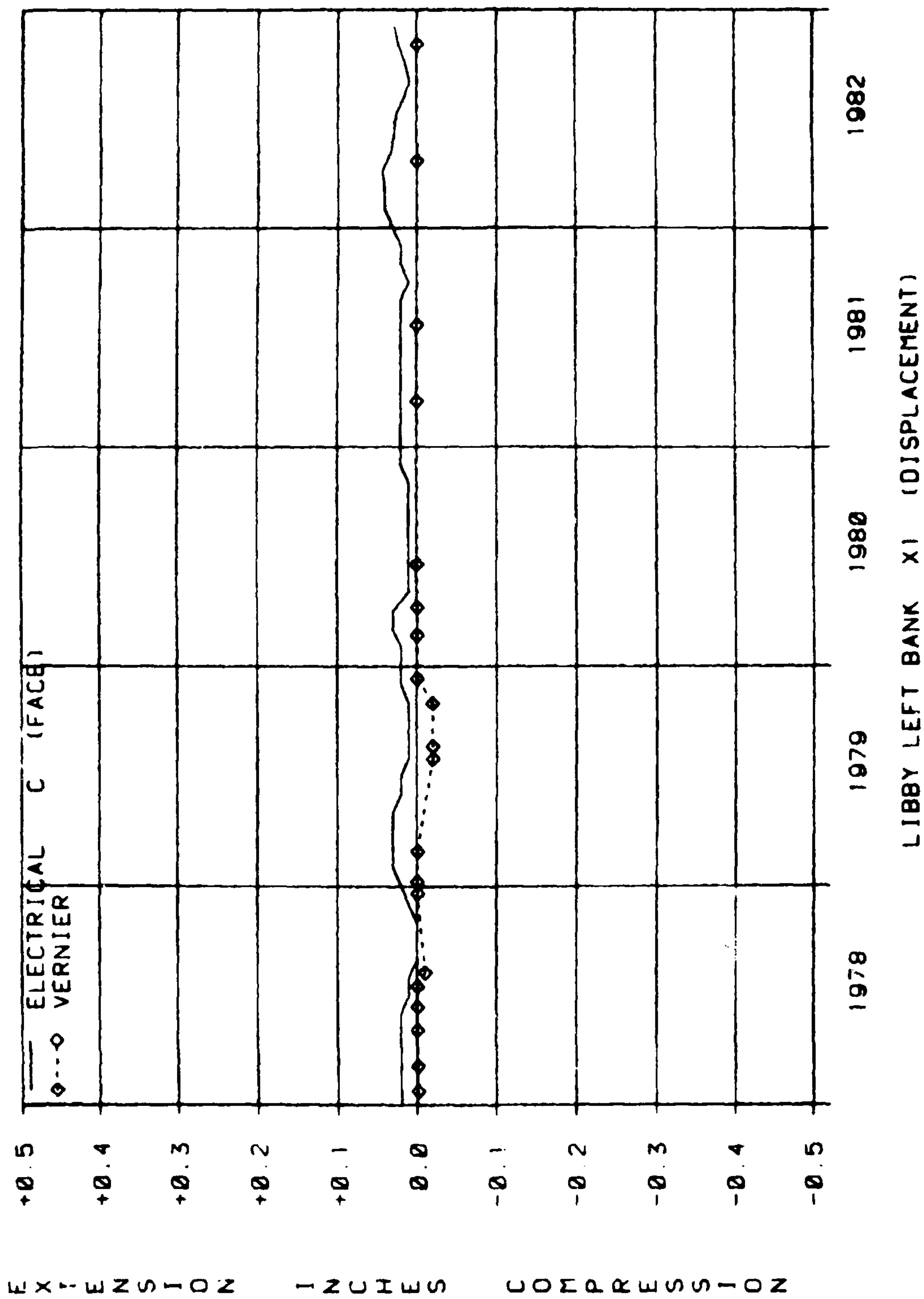
PP-20

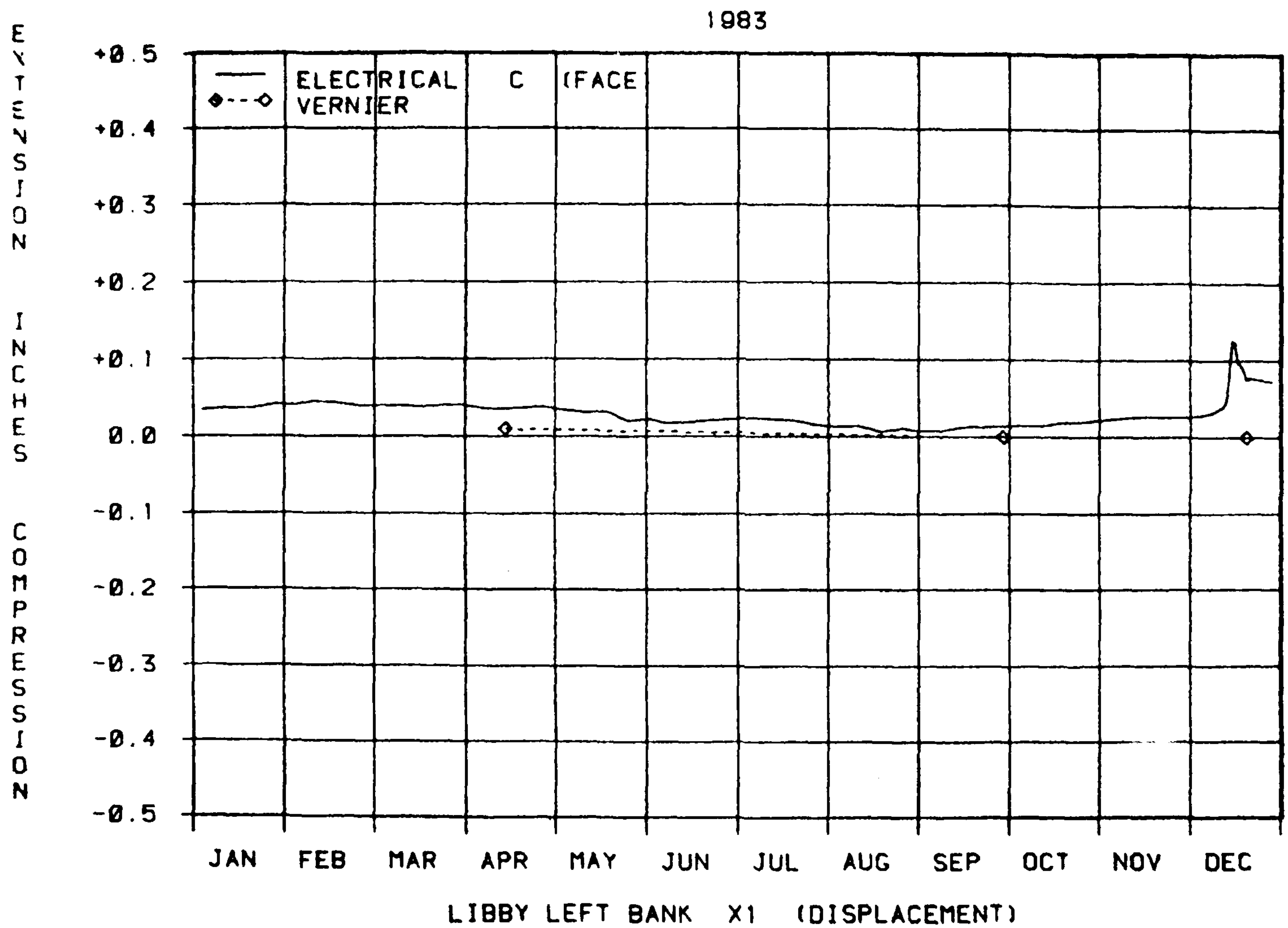

ELEV. 2011
PP-21-1
NC
H ELEV. 2507
PP-21-2
914 FAULT
PLAN
PP-21-7
PP-21
PP-21A
PP-21-5
ELEV. 2225
PP-21-4A
PP-21-3A
PP-21-6
PP-21-6
PP-21
MATCH LINE
PP-21-5
PP-21-2
PP-21-3A
PROFILE
PP-21-7
PP-21-4A
ELEV. 2225
PP-21
PP-21-1
ELEV. 2011
MATCH
PP-2


ELEV.
DEPTH
2483
0
PP-22 INST.
PP-22-6
2400
100
PP-22-5
909 FAULT
PP-22-4
PP-22-3
2300
200
PP-22-2
PP-22-1

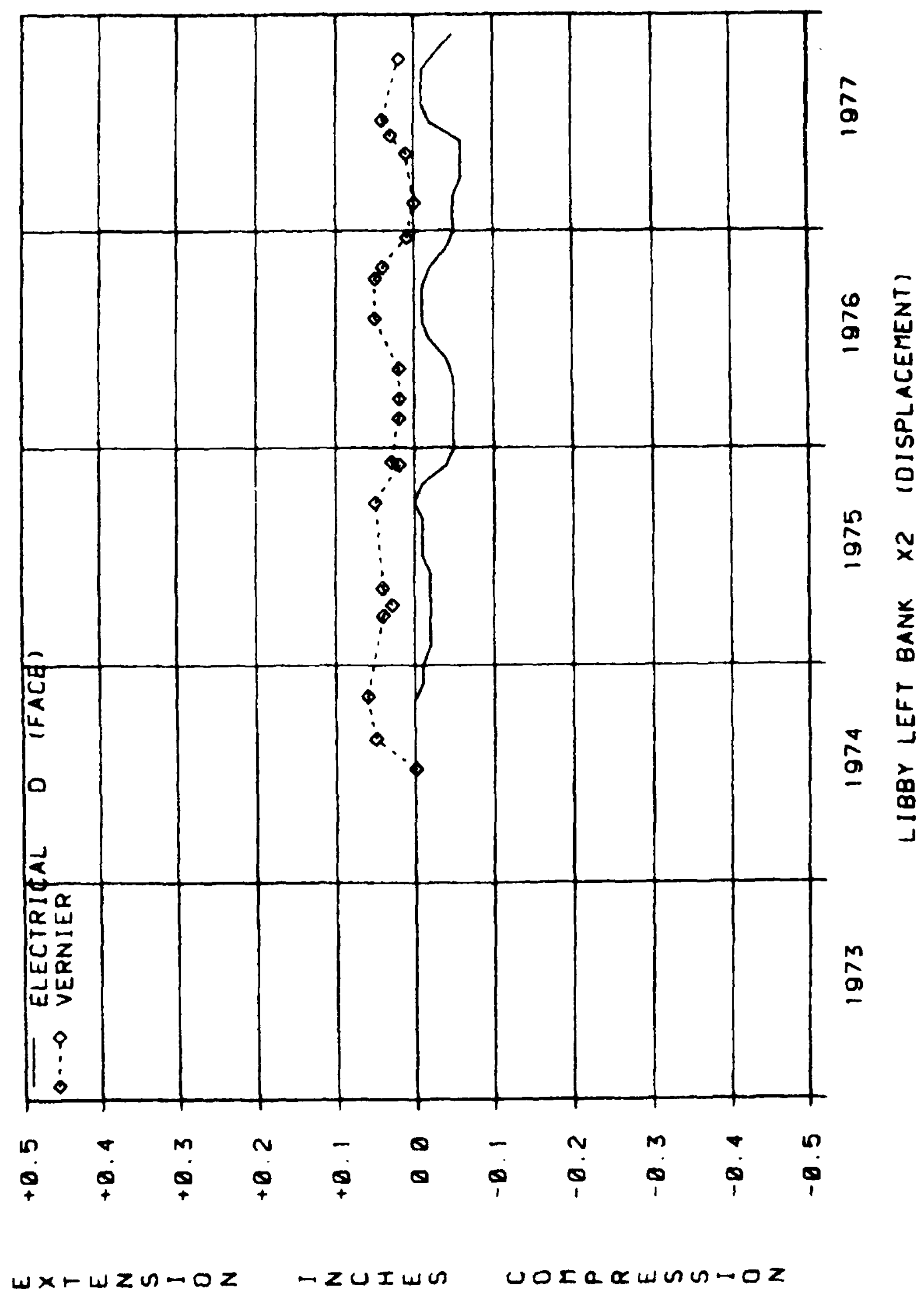
Appendix B - Instrumental Plots -
MPBX (L) and X Extensometer


ELECTRICAL C (FACE)
VERNIER
+0.5
+0.4
+0.3
+0.2
+0.1
0.0
-0.1
-0.2
-0.3
-0.4
-0.5
EXTENSION
INCHES
COMPRESSION
1973
1974
1975
1976
1977
LIBBY LEFT BANK X1 (DISPLACEMENT)

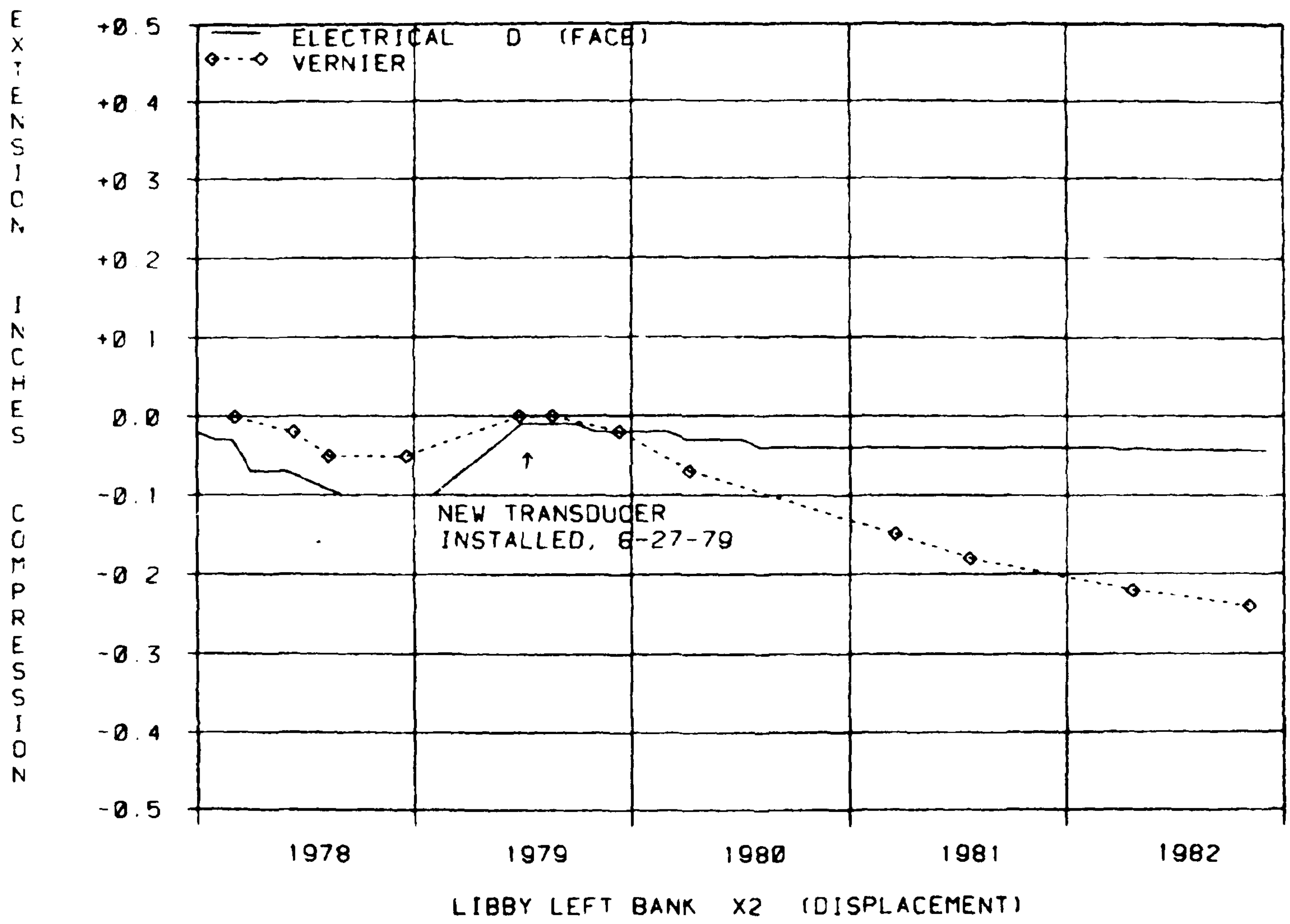

ELECTRICAL C (FACE)
VERNIER
1978
1979
1980
1981
1982
LIBBY LEFT BANK X1 (DISPLACEMENT)
+0.5
+0.4
+0.3
+0.2
+0.1
0.0
-0.1
-0.2
-0.3
-0.4
-0.5
EXTENSION INCHES COMPRESSION

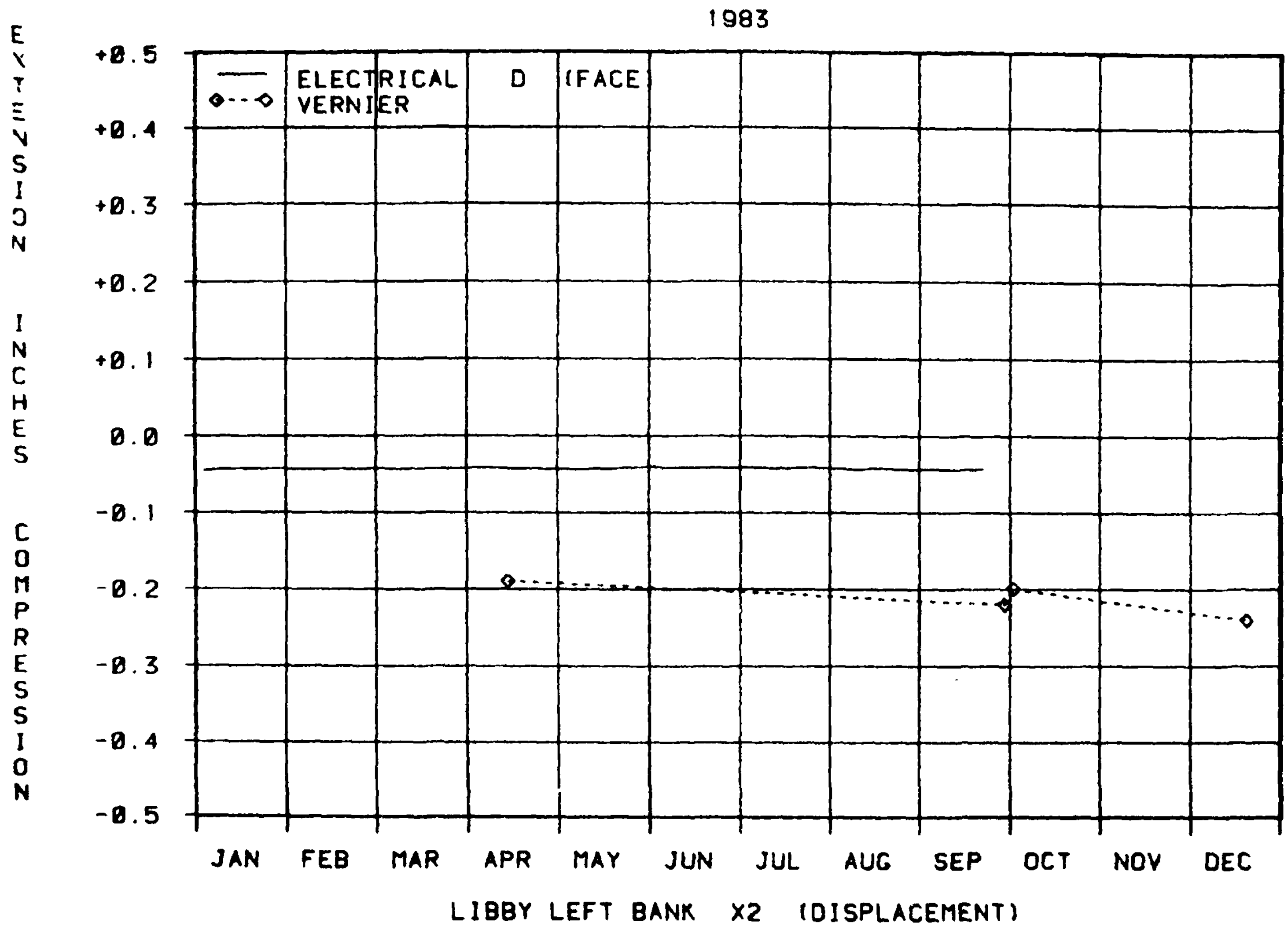


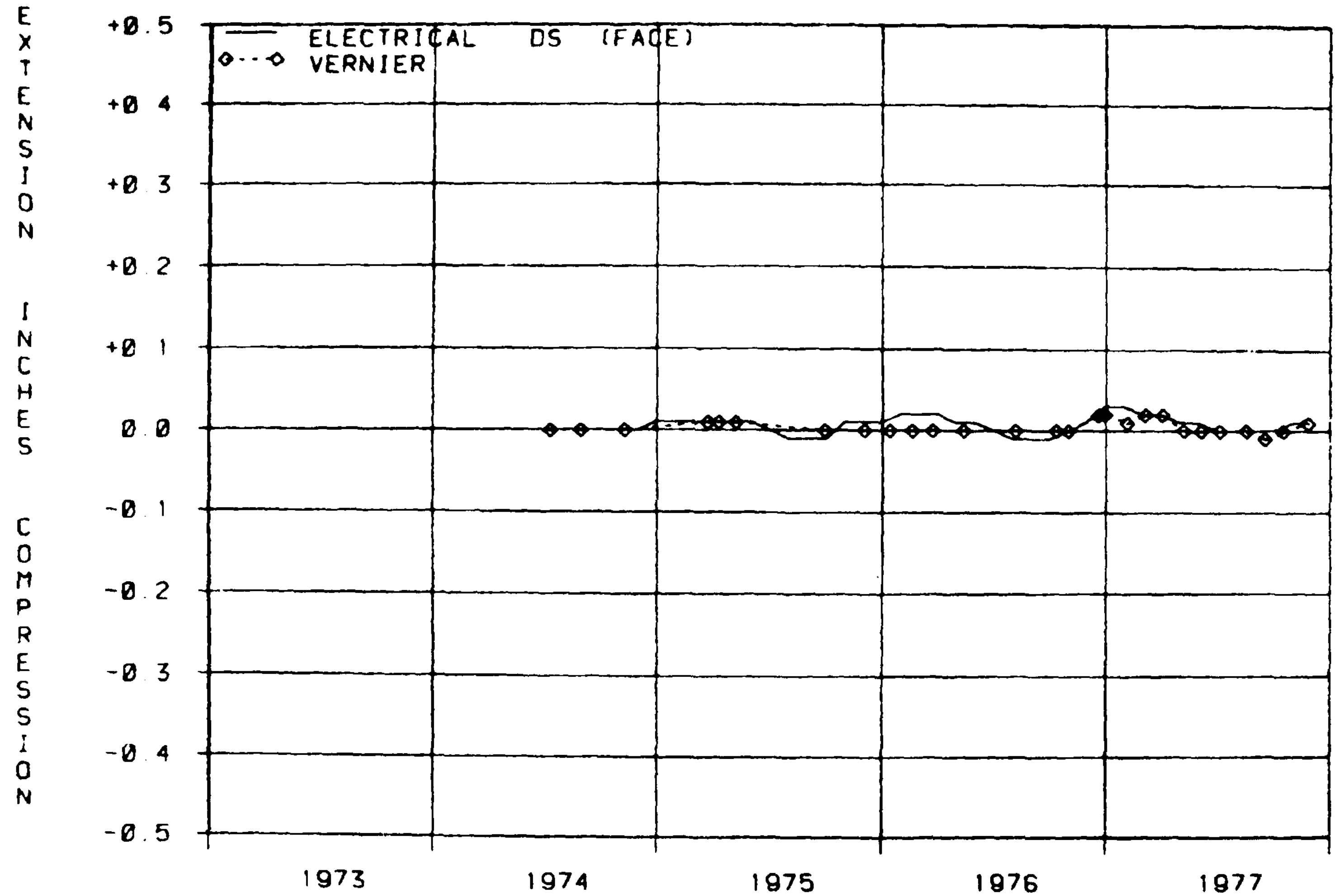
1983
ELECTRICAL C (FACE
VERNIER
EXTENSION INCHES COMPRESSION
+0.5
+0.4
+0.3
+0.2
+0.1
0.0
-0.1
-0.2
-0.3
-0.4
-0.5
JAN FEB MAR APR MAY JUN JUL AUG SEP OCT NOV DEC
LIBBY LEFT BANK X1 (DISPLACEMENT)



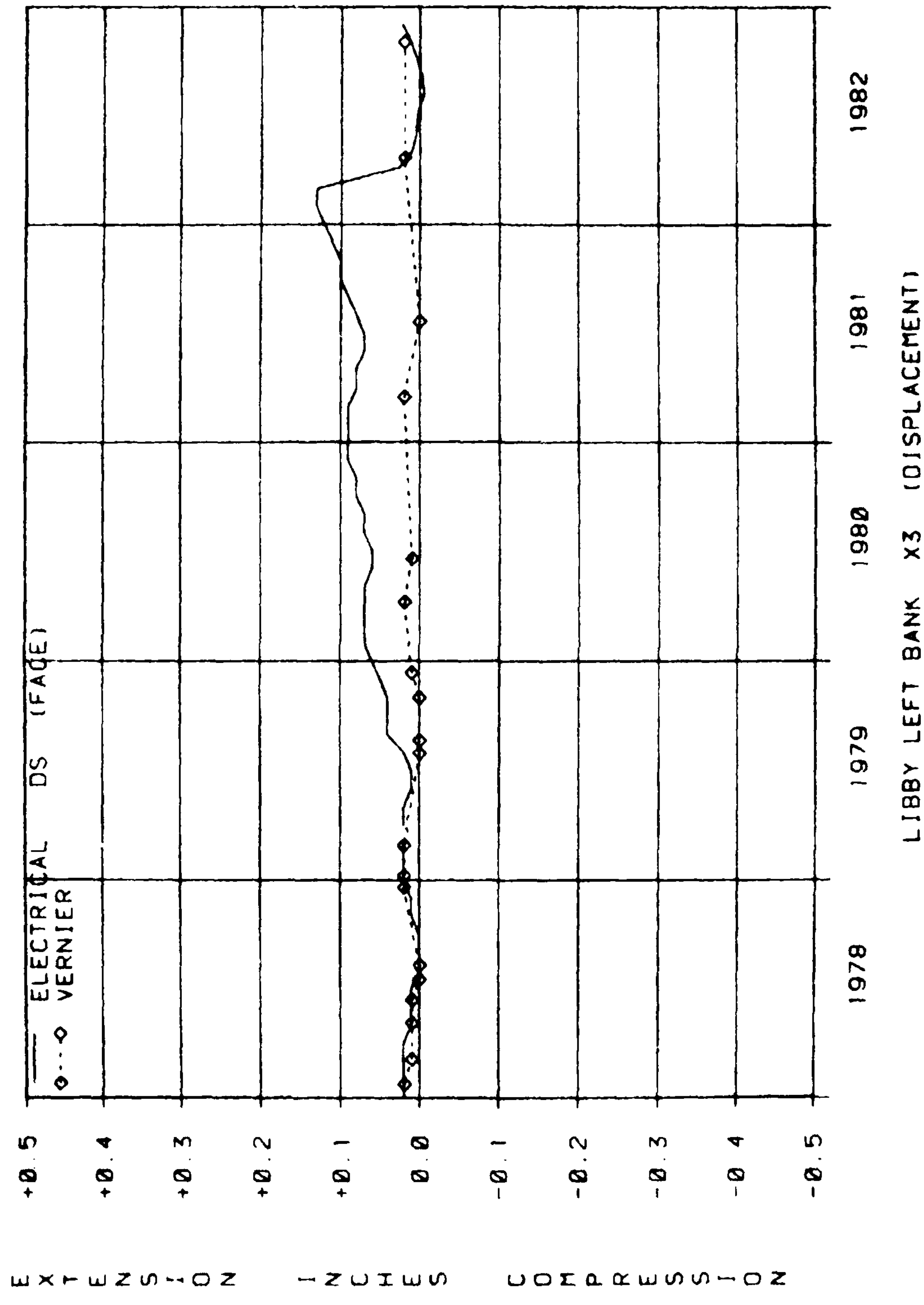
ELECTRICAL D (FACE)
VERNIER
+0.5
+0.4
+0.3
+0.2
+0.1
0.0
-0.1
-0.2
-0.3
-0.4
-0.5
EXTENSION INCHES COMPRESSION
1973
1974
1975
1976
1977
LIBBY LEFT BANK X2 (DISPLACEMENT)

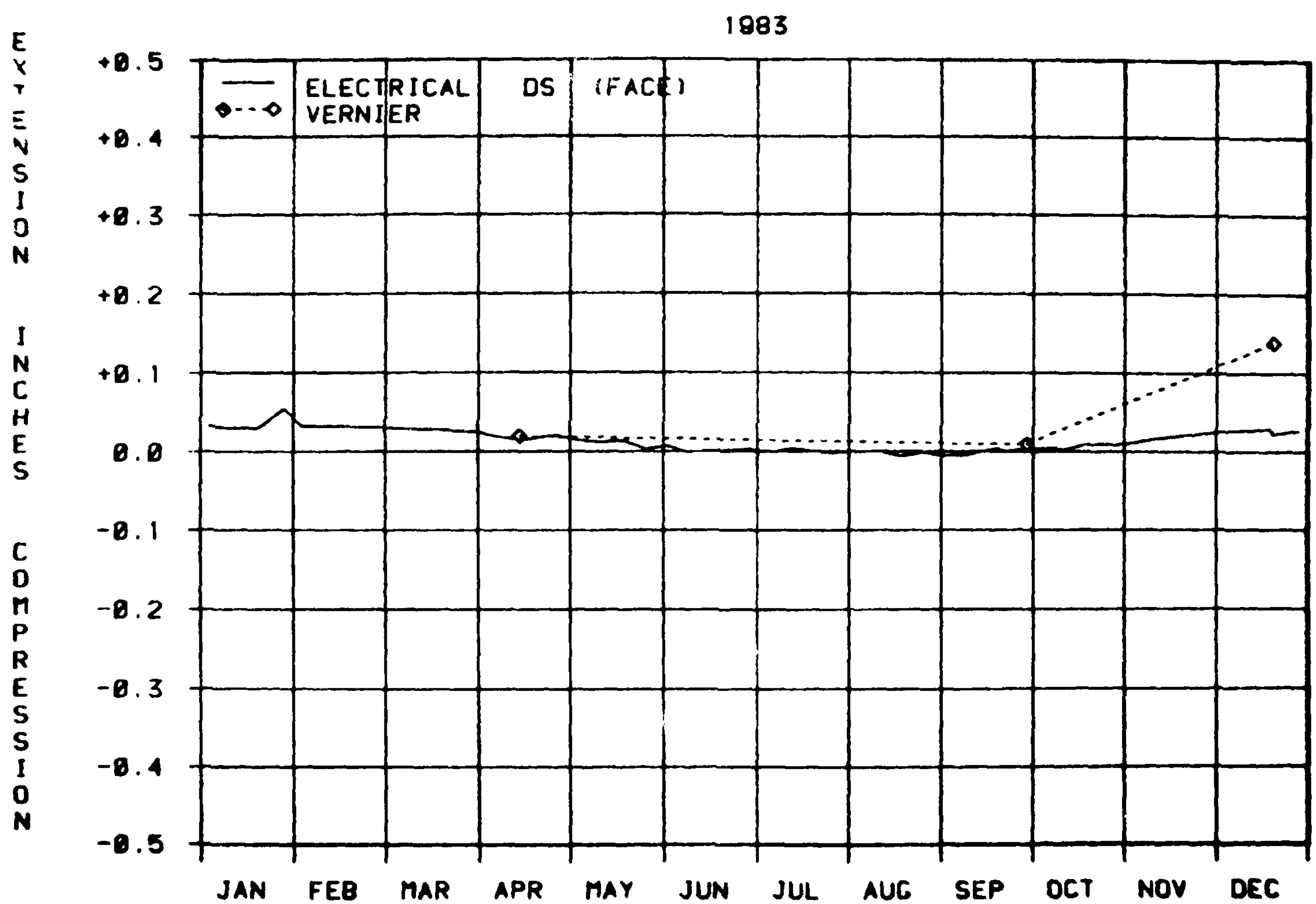

ELECTRICAL D (FACE)
VERNIER
EXTENSION INCHES COMPRESSION
+0.5
+0.4
+0.3
+0.2
+0.1
0.0
-0.1
-0.2
-0.3
-0.4
-0.5
NEW TRANSDUCER
INSTALLED, 8-27-79
1978
1979
1980
1981
1982
LIBBY LEFT BANK X2 (DISPLACEMENT)


1983
ELECTRICAL D (FACE)
VERNIER
+0.5
+0.4
+0.3
+0.2
+0.1
0.0
-0.1
-0.2
-0.3
-0.4
-0.5
EXTENSION INCHES COMPRESSION
JAN FEB MAR APR MAY JUN JUL AUG SEP OCT NOV DEC
LIBBY LEFT BANK X2 (DISPLACEMENT)

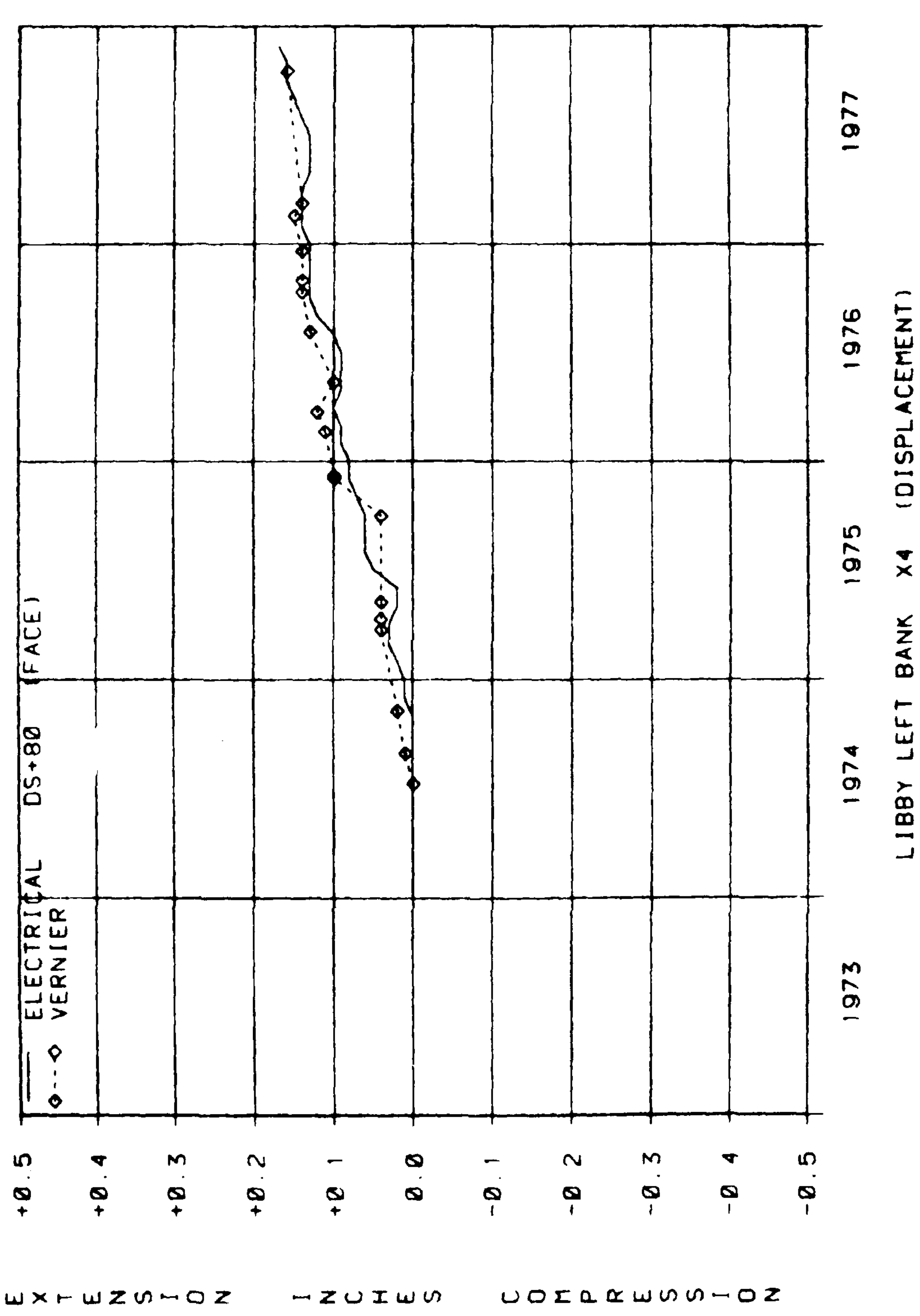


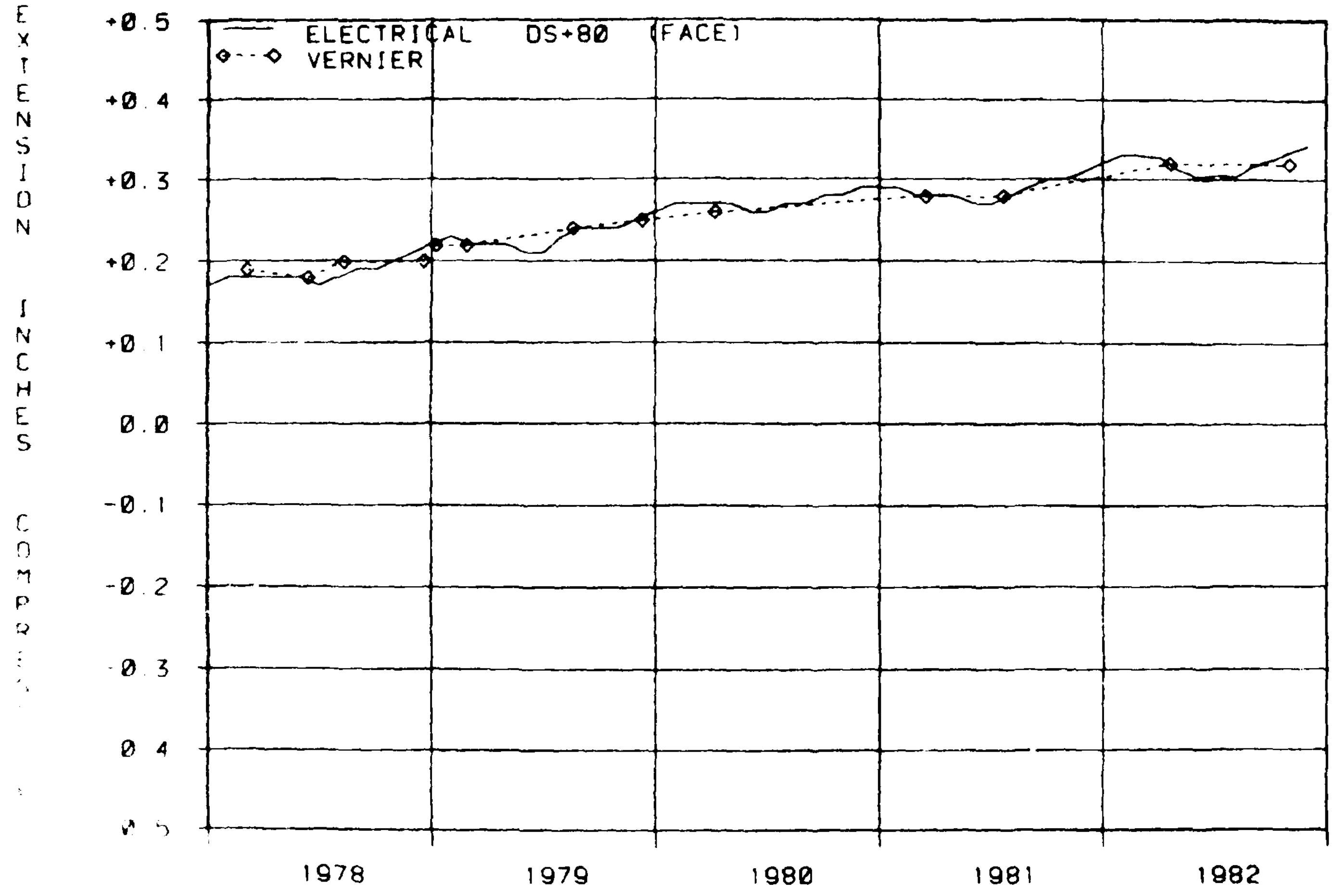
LIBBY LEFT BANK X3 (DISPLACEMENT)


ELECTRICAL DS (FACE)
VERNIER
+0.5
+0.4
+0.3
+0.2
+0.1
0.0
-0.1
-0.2
-0.3
-0.4
-0.5
EXTENSION INCHES COMPRESSION
1978
1979
1980
1981
1982
LIBBY LEFT BANK X3 (DISPLACEMENT)



LIBBY LEFT BANK X3 (DISPLAC_MENT)


LIBBY LEFT BANK X4 (DISPLACEMENT)
DS+80 (FACE)
ELECTRICAL
VERNIER
1973
1974
1975
1976
1977
+0.5
+0.4
+0.3
+0.2
+0.1
0.0
-0.1
-0.2
-0.3
-0.4
-0.5
EXTENSION INCHES COMPRESSION

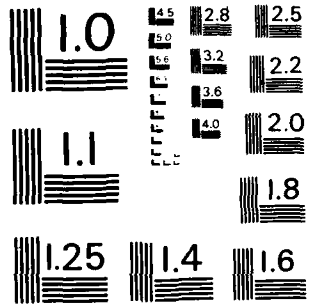


LIBBY LEFT BANK X4 (DISPLACEMENT)

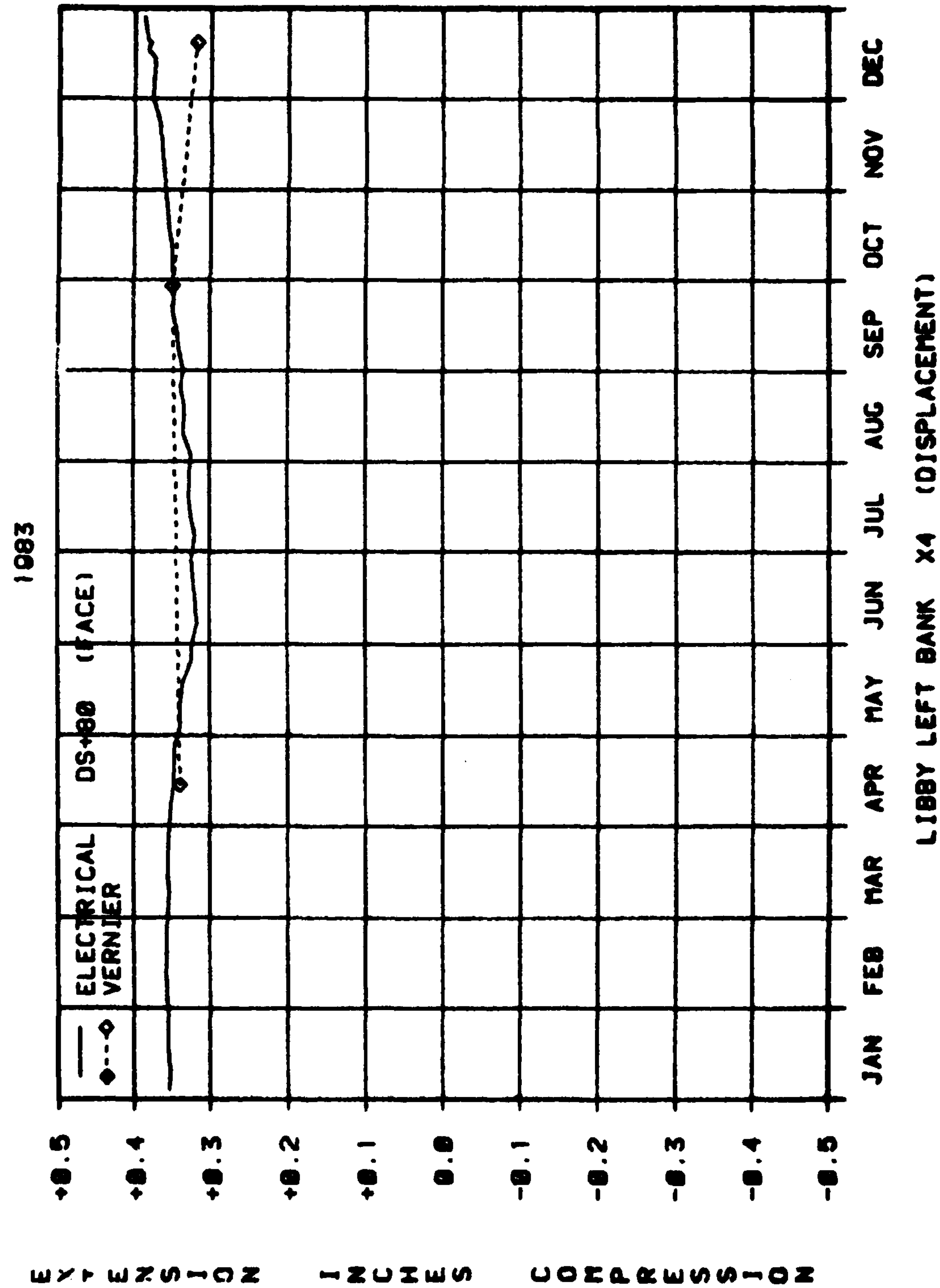
AD-A142 021 LIBBY DAM AND LAKE KOOCANUSA PROJECT MONTANA LEFT BANK SLOPE(U) CORPS OF ENGINEERS SEATTLE WA SEATTLE DISTRICT APR 84

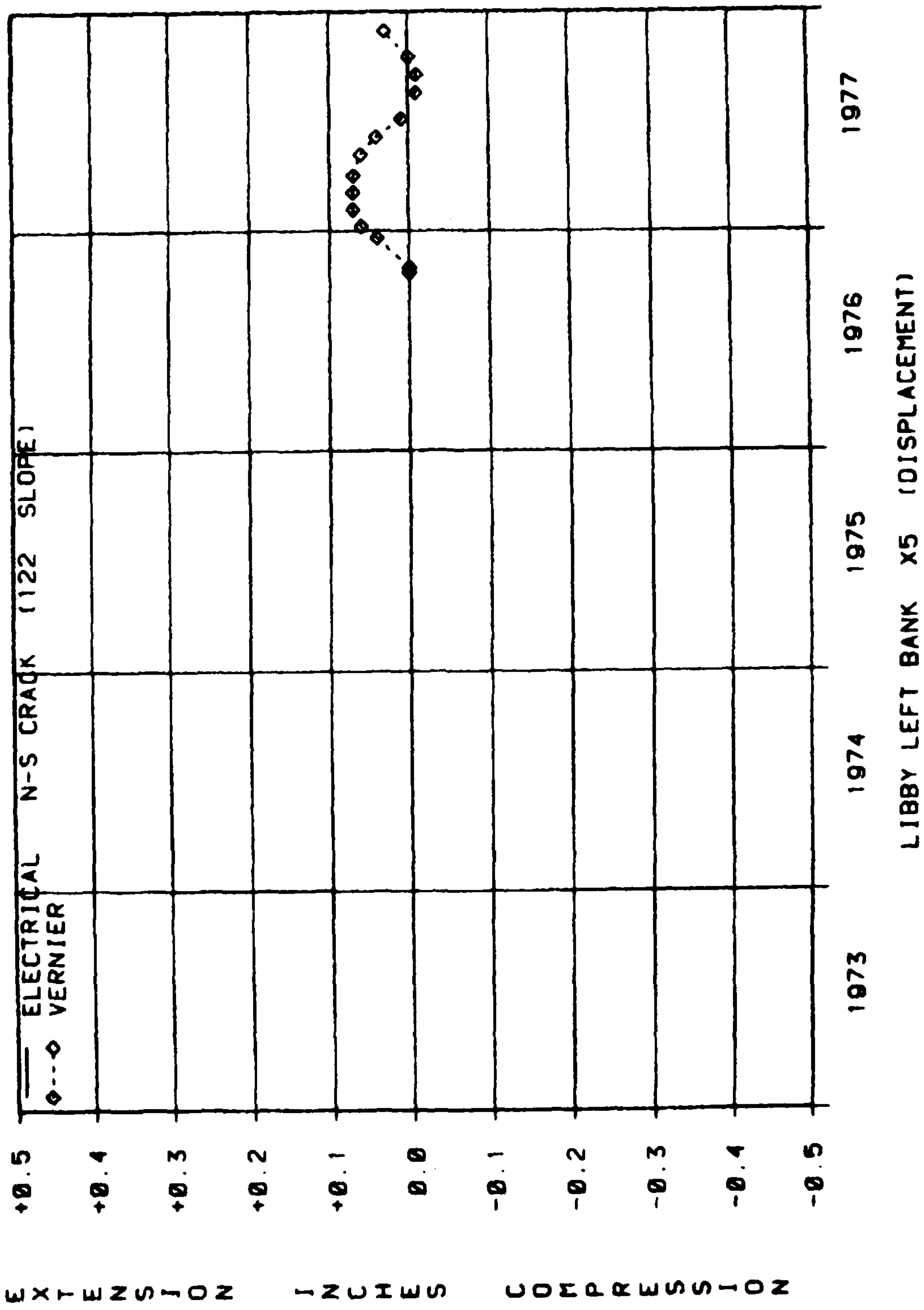
3/6

UNCLASSIFIED F/G 13/2 NL

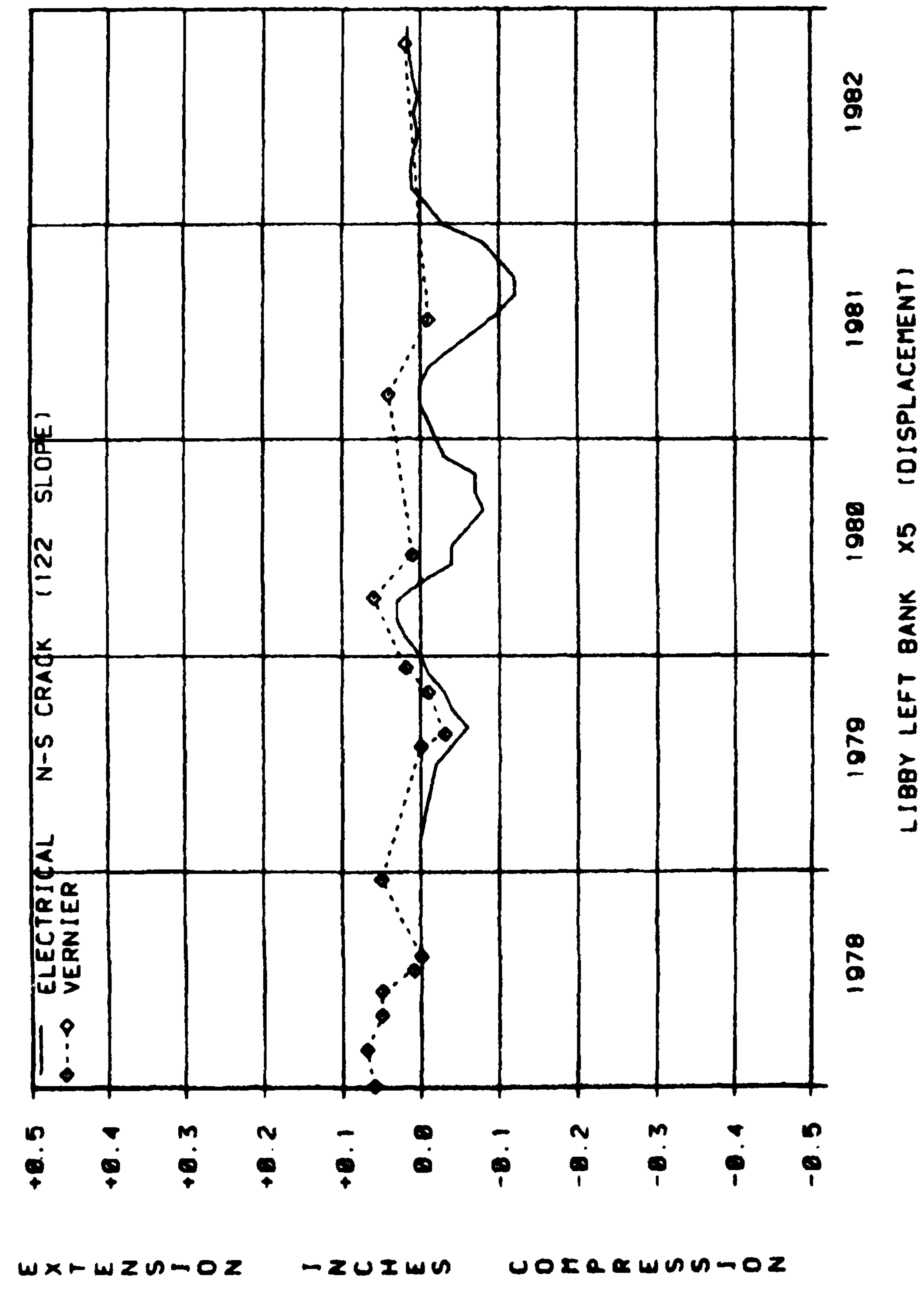


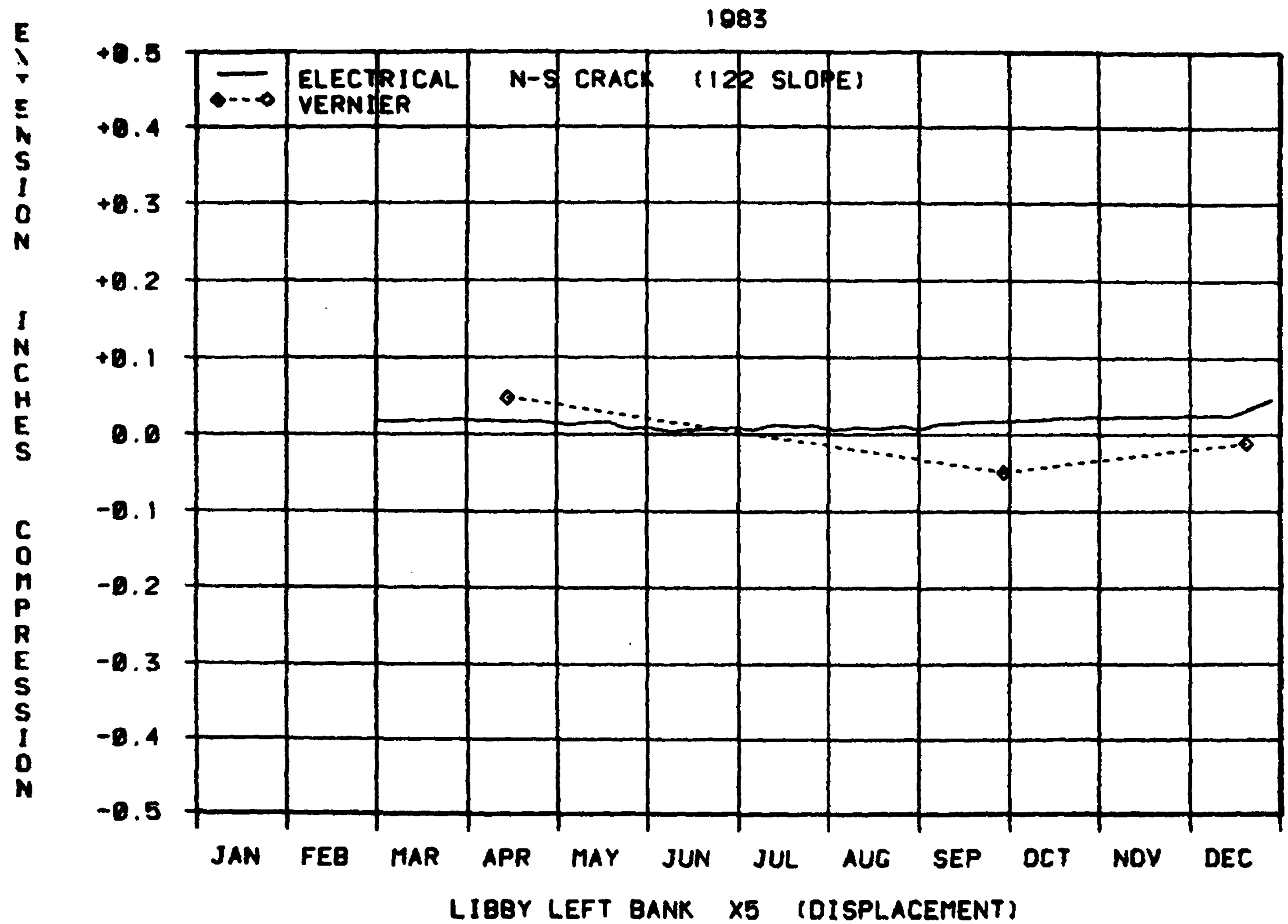
MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A


1983
ELECTRICAL
VERNIER
DS+80 (FACE)
JAN FEB MAR APR MAY JUN JUL AUG SEP OCT NOV DEC
LIBBY LEFT BANK X4 (DISPLACEMENT)
+0.5 +0.4 +0.3 +0.2 +0.1 0.0 -0.1 -0.2 -0.3 -0.4 -0.5
EXTENSION INCHES COMPRESSION

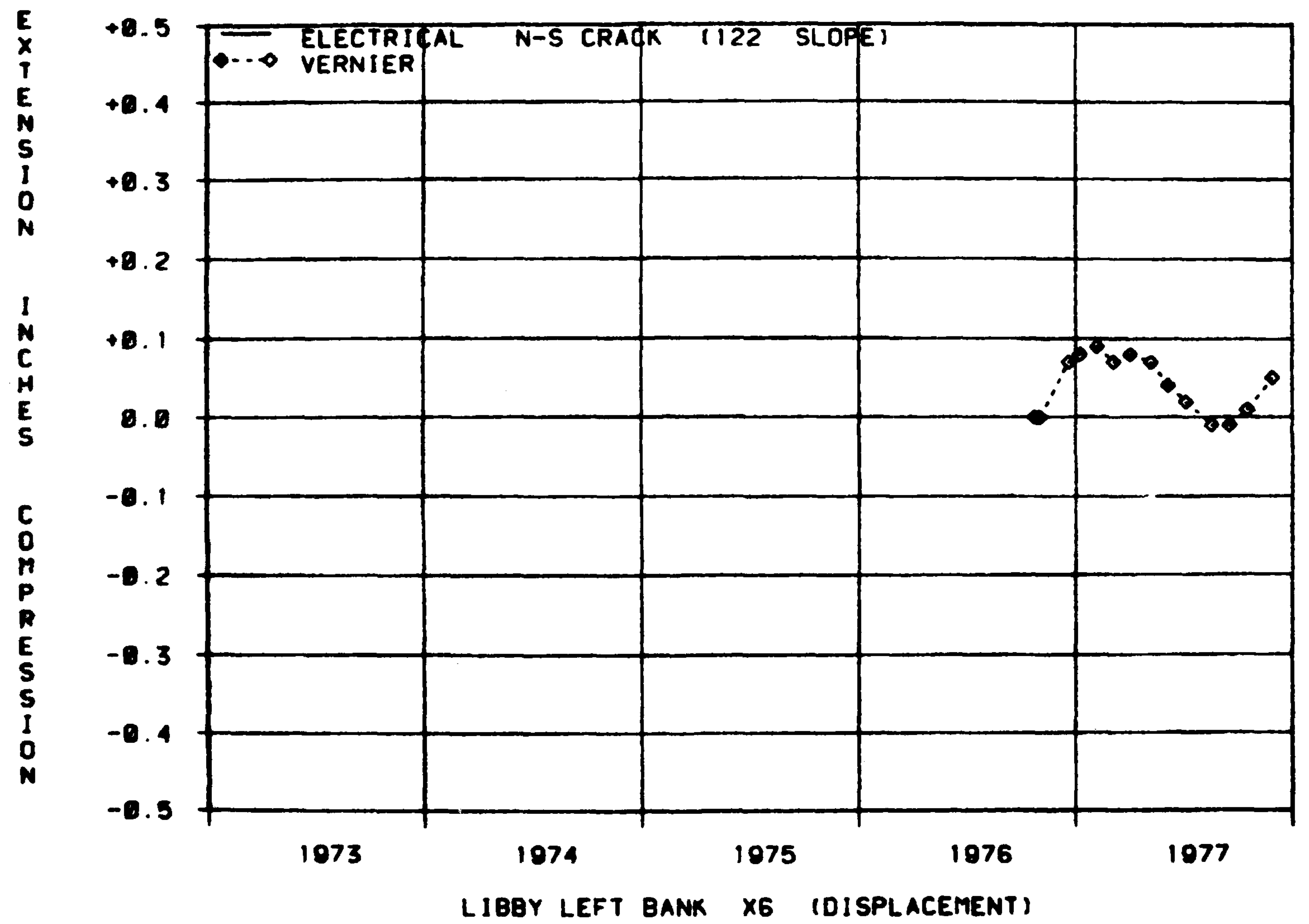


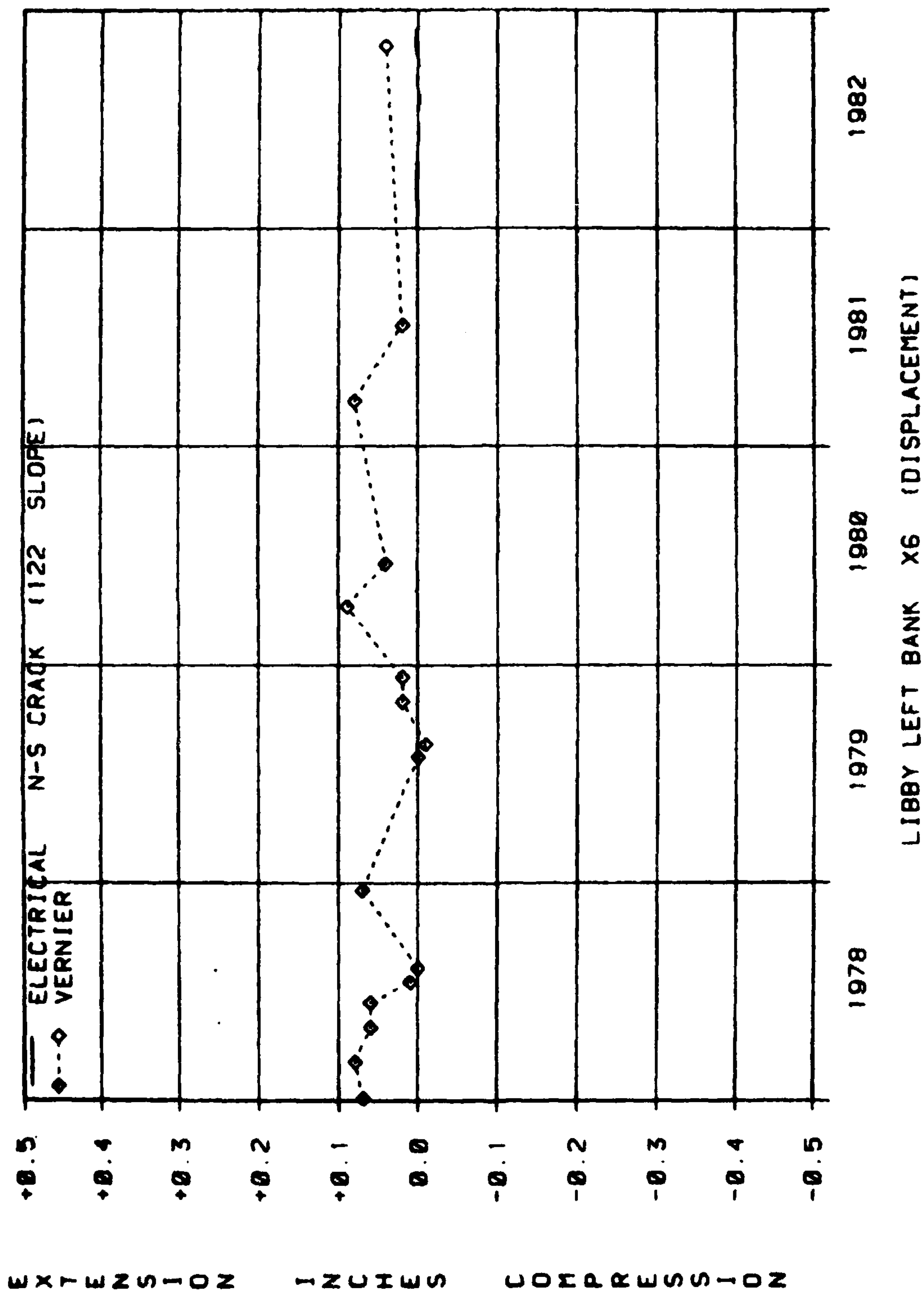
ELECTRICAL
VERNIER
N-S CRACK (122 SLOPE)
LIBBY LEFT BANK X5 (DISPLACEMENT)
1973
1974
1975
1976
1977
+0.5
+0.4
+0.3
+0.2
+0.1
0.0
-0.1
-0.2
-0.3
-0.4
-0.5
EXTENSION INCHES COMPRESSION

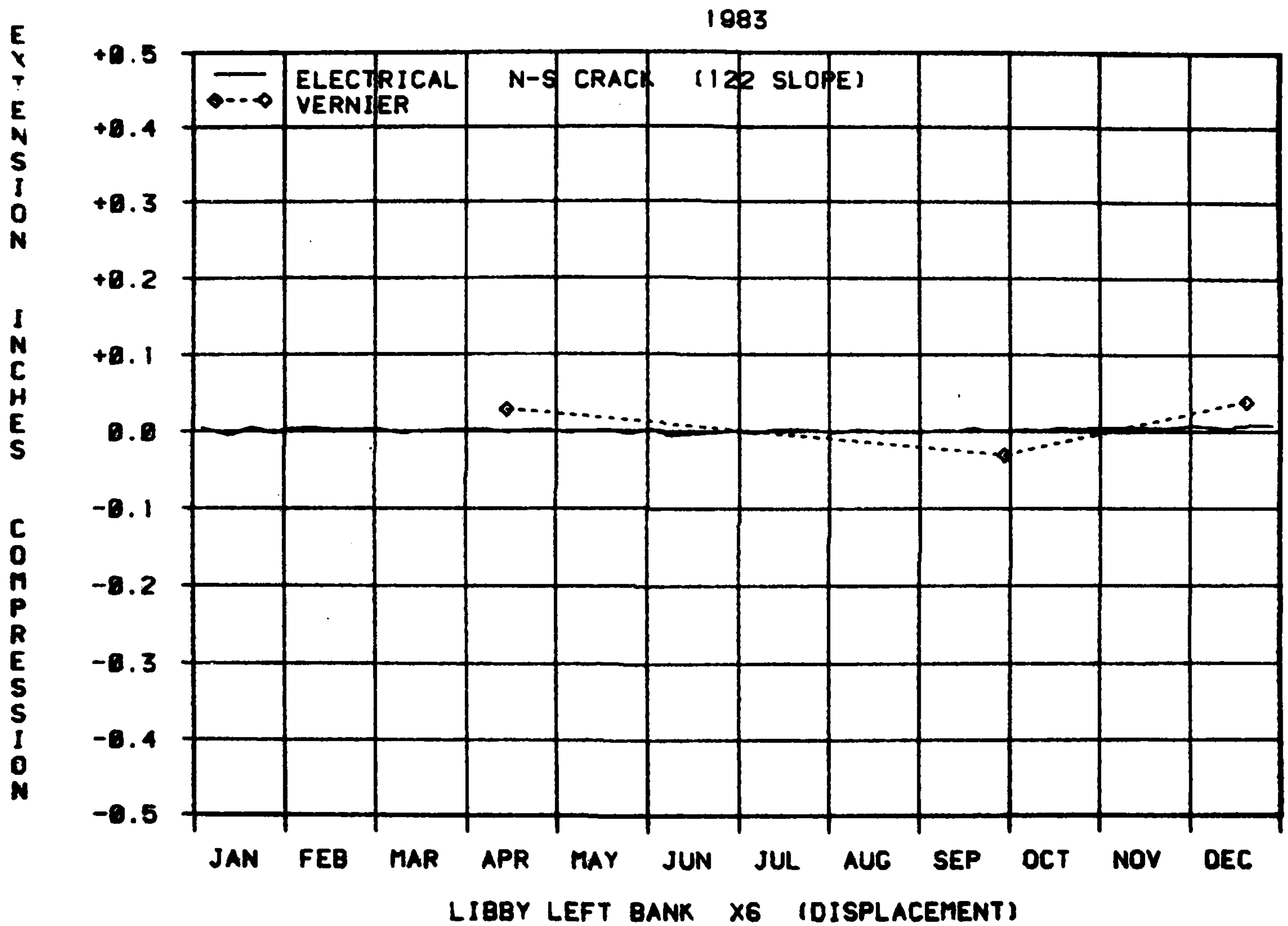

ELECTRICAL N-S CRACK (122 SLOPE)
VERNIER
+0.5
+0.4
+0.3
+0.2
+0.1
0.0
-0.1
-0.2
-0.3
-0.4
-0.5
EXTENSION INCHES COMPRESSION
1978
1979
1980
1981
1982
LIBBY LEFT BANK X5 (DISPLACEMENT)

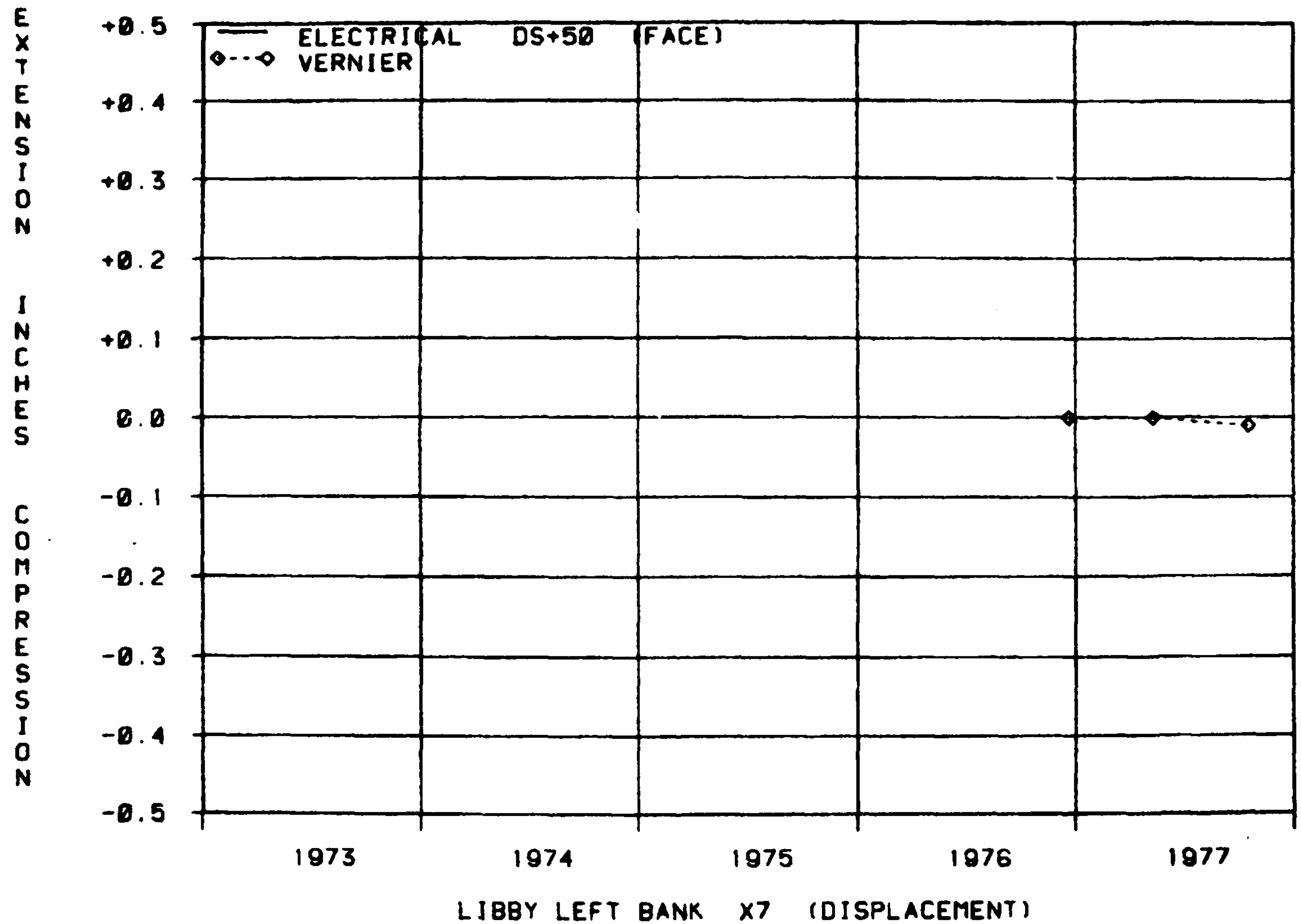


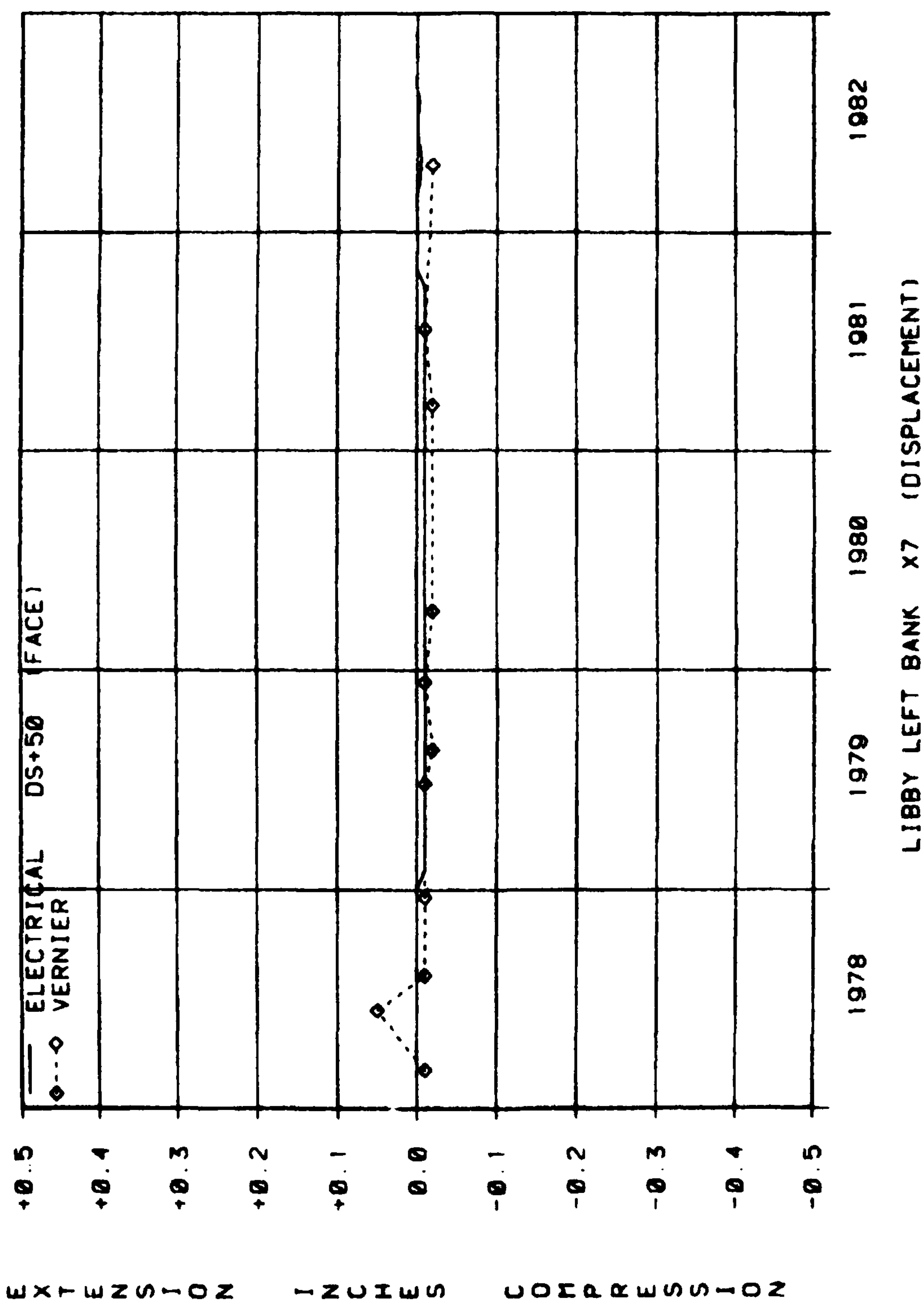
1983
ELECTRICAL
VERNIER
N-S CRACK (122 SLOPE)
EXTENSION INCHES COMPRESSION
+0.5
+0.4
+0.3
+0.2
+0.1
0.0
-0.1
-0.2
-0.3
-0.4
-0.5
JAN FEB MAR APR MAY JUN JUL AUG SEP OCT NOV DEC
LIBBY LEFT BANK X5 (DISPLACEMENT)


ELECTRICAL N-S CRACK (122 SLOPE)
VERNIER
+0.5
+0.4
+0.3
+0.2
+0.1
0.0
-0.1
-0.2
-0.3
-0.4
-0.5
EXTENSION INCHES COMPRESSION
1973
1974
1975
1976
1977
LIBBY LEFT BANK X6 (DISPLACEMENT)

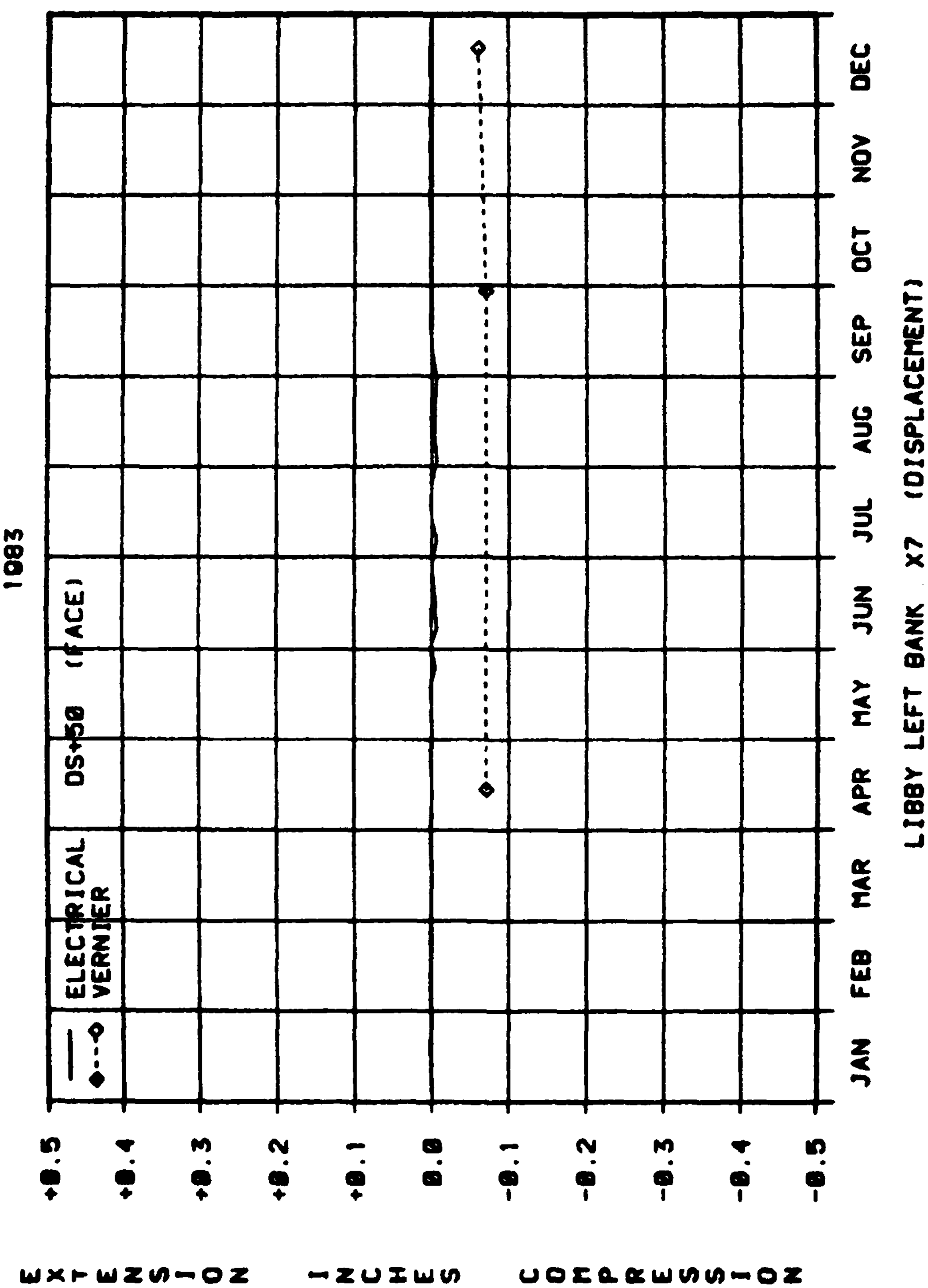

ELECTRICAL N-S CRACK (122 SLOPE)
VERNIER
+0.5
+0.4
+0.3
+0.2
+0.1
0.0
-0.1
-0.2
-0.3
-0.4
-0.5
EXTENSION INCHES COMPRESSION
1978
1979
1980
1981
1982
LIBBY LEFT BANK X6 (DISPLACEMENT)

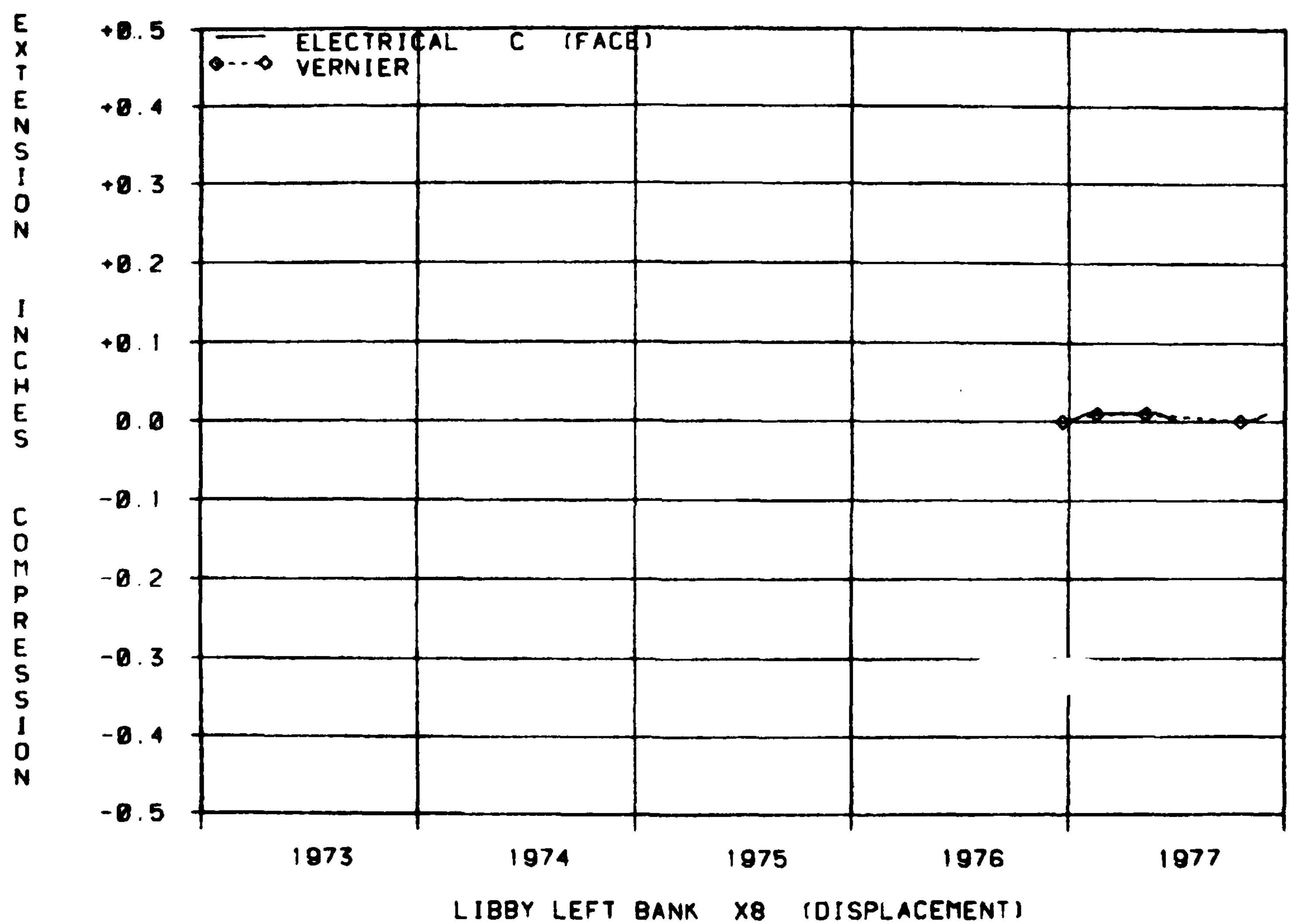

1983
ELECTRICAL
VERNIER
N-S CRACK (122 SLOPE)
EXTENSION INCHES COMPRESSION
+0.5
+0.4
+0.3
+0.2
+0.1
0.0
-0.1
-0.2
-0.3
-0.4
-0.5
JAN FEB MAR APR MAY JUN JUL AUG SEP OCT NOV DEC
LIBBY LEFT BANK X6 (DISPLACEMENT)

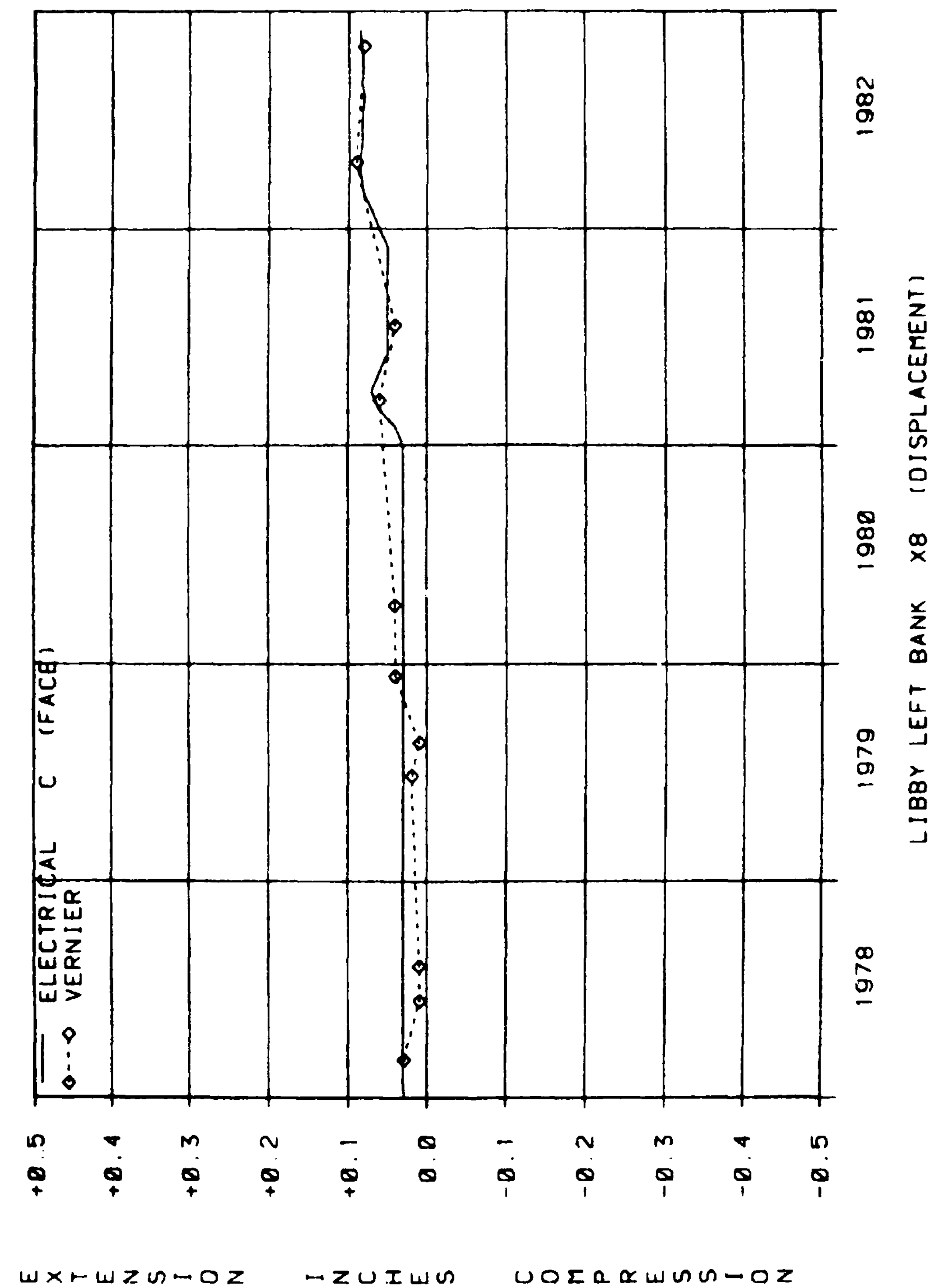

ELECTRICAL DS+50 (FACE)
VERNIER
EXTENSION INCHES COMPRESSION
+0.5
+0.4
+0.3
+0.2
+0.1
0.0
-0.1
-0.2
-0.3
-0.4
-0.5
1973
1974
1975
1976
1977
LIBBY LEFT BANK X7 (DISPLACEMENT)

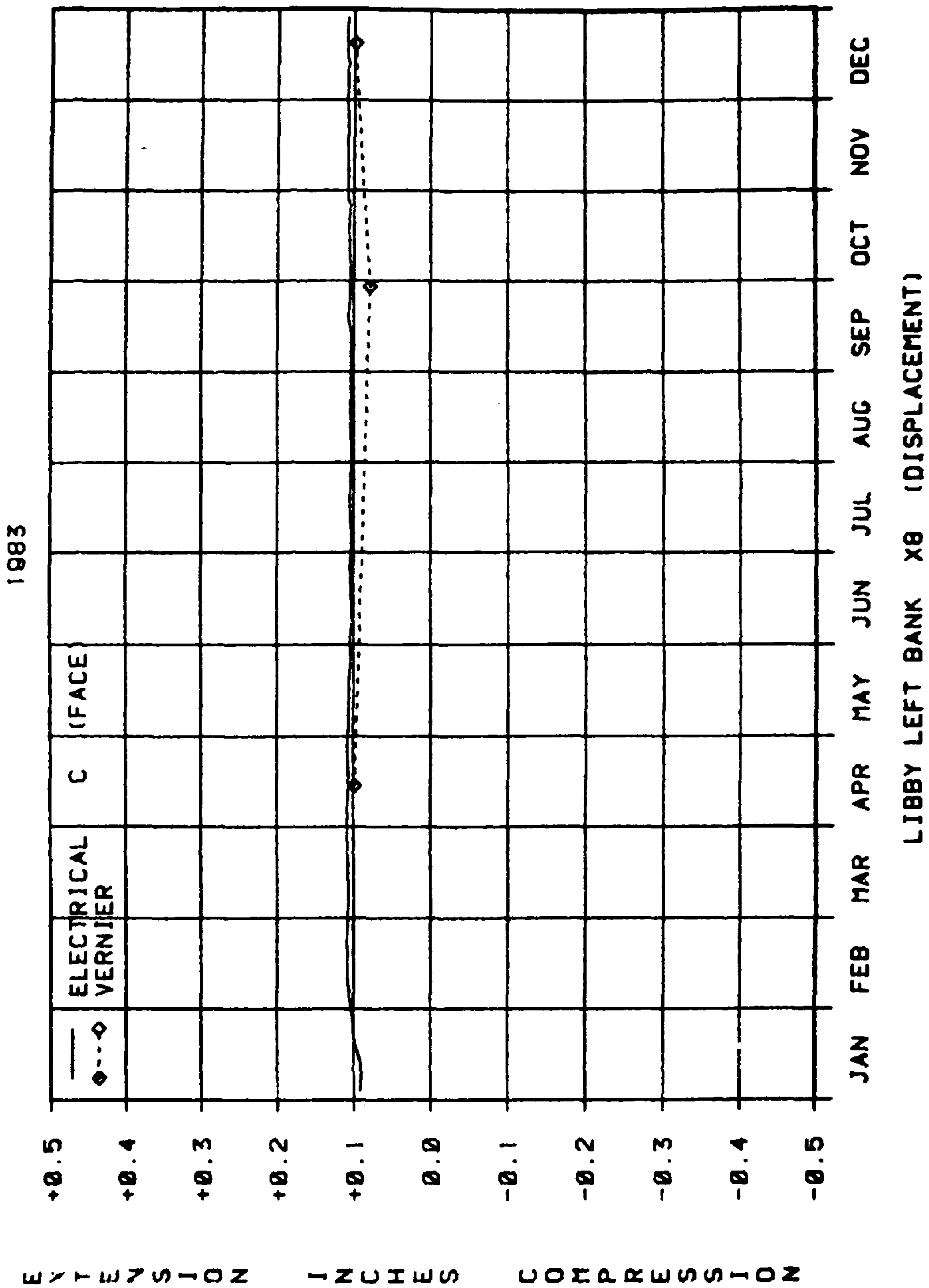


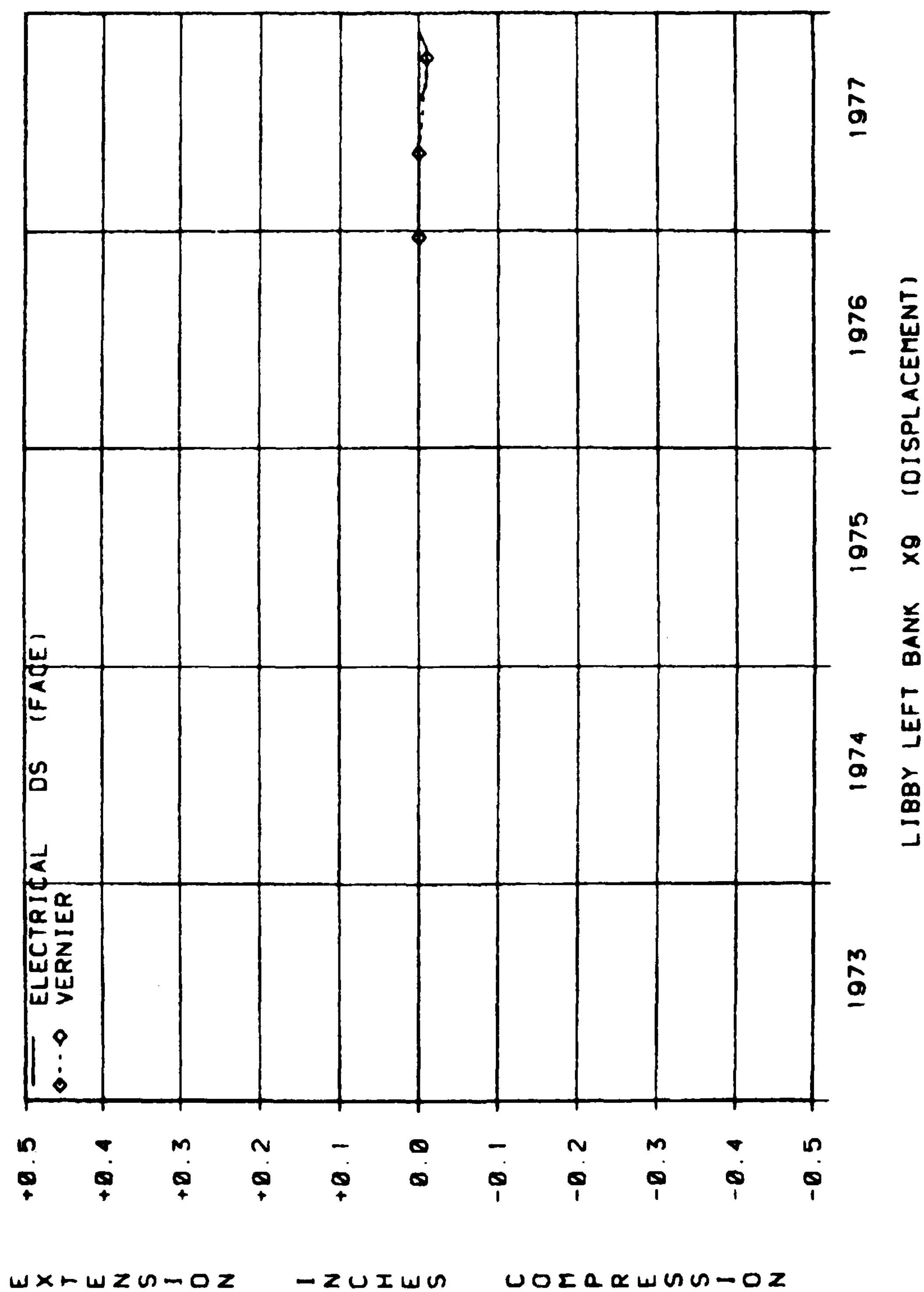
ELECTRICAL
VERNIER
DS+50 (FACE)
+0.5
+0.4
+0.3
+0.2
+0.1
0.0
-0.1
-0.2
-0.3
-0.4
-0.5
EXTENSION INCHES COMPRESSION
1978
1979
1980
1981
1982
LIBBY LEFT BANK X7 (DISPLACEMENT)


1983
ELECTRICAL
VERNIER
DS+50 (FACE)
+0.5
+0.4
+0.3
+0.2
+0.1
0.0
-0.1
-0.2
-0.3
-0.4
-0.5
EXTENSION INCHES COMPRESSION
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC
LIBBY LEFT BANK X7 (DISPLACEMENT)

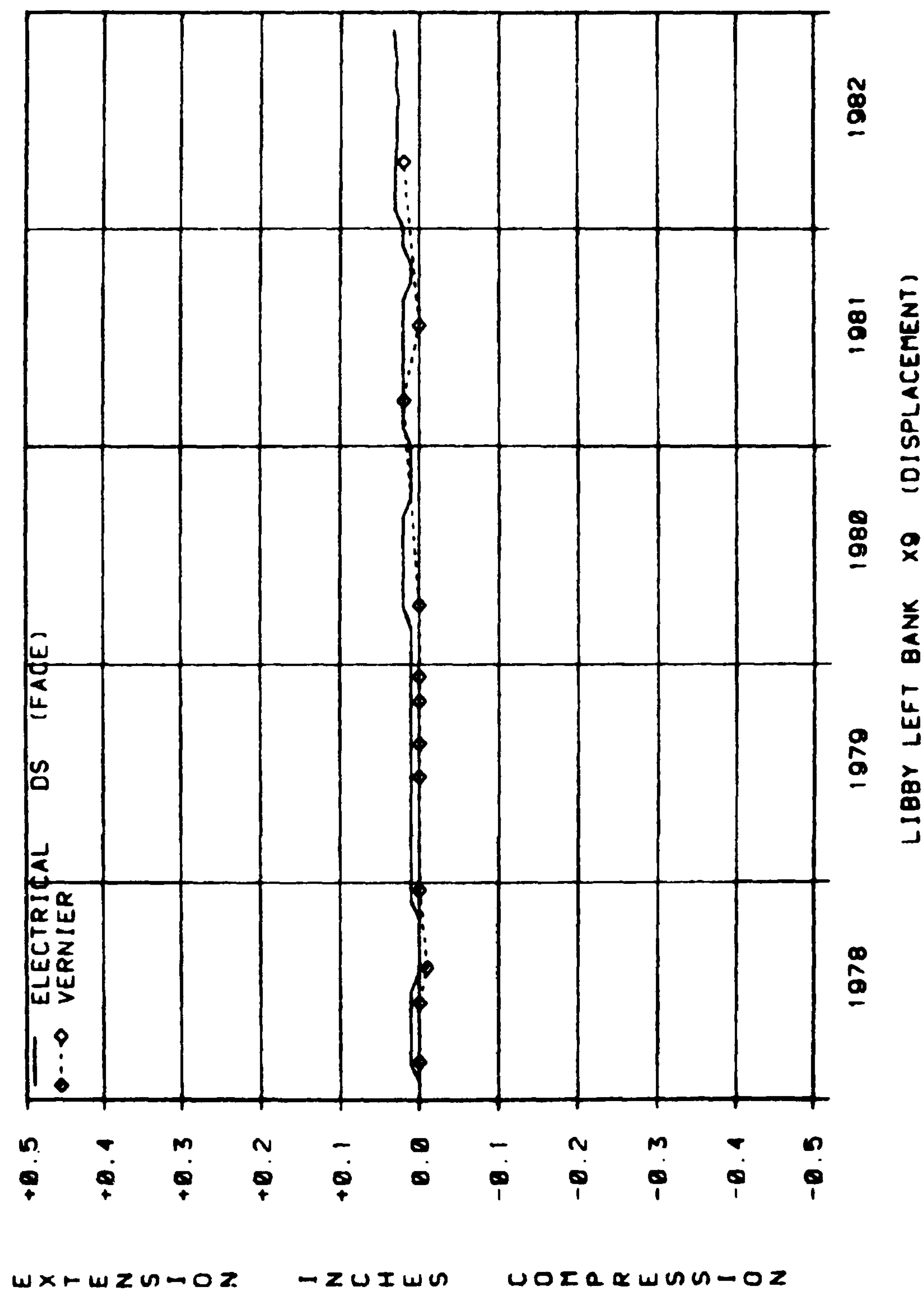

ELECTRICAL C (FACE)
VERNIER
EXTENSION INCHES COMPRESSION
+0.5
+0.4
+0.3
+0.2
+0.1
0.0
-0.1
-0.2
-0.3
-0.4
-0.5
1973
1974
1975
1976
1977
LIBBY LEFT BANK X8 (DISPLACEMENT)

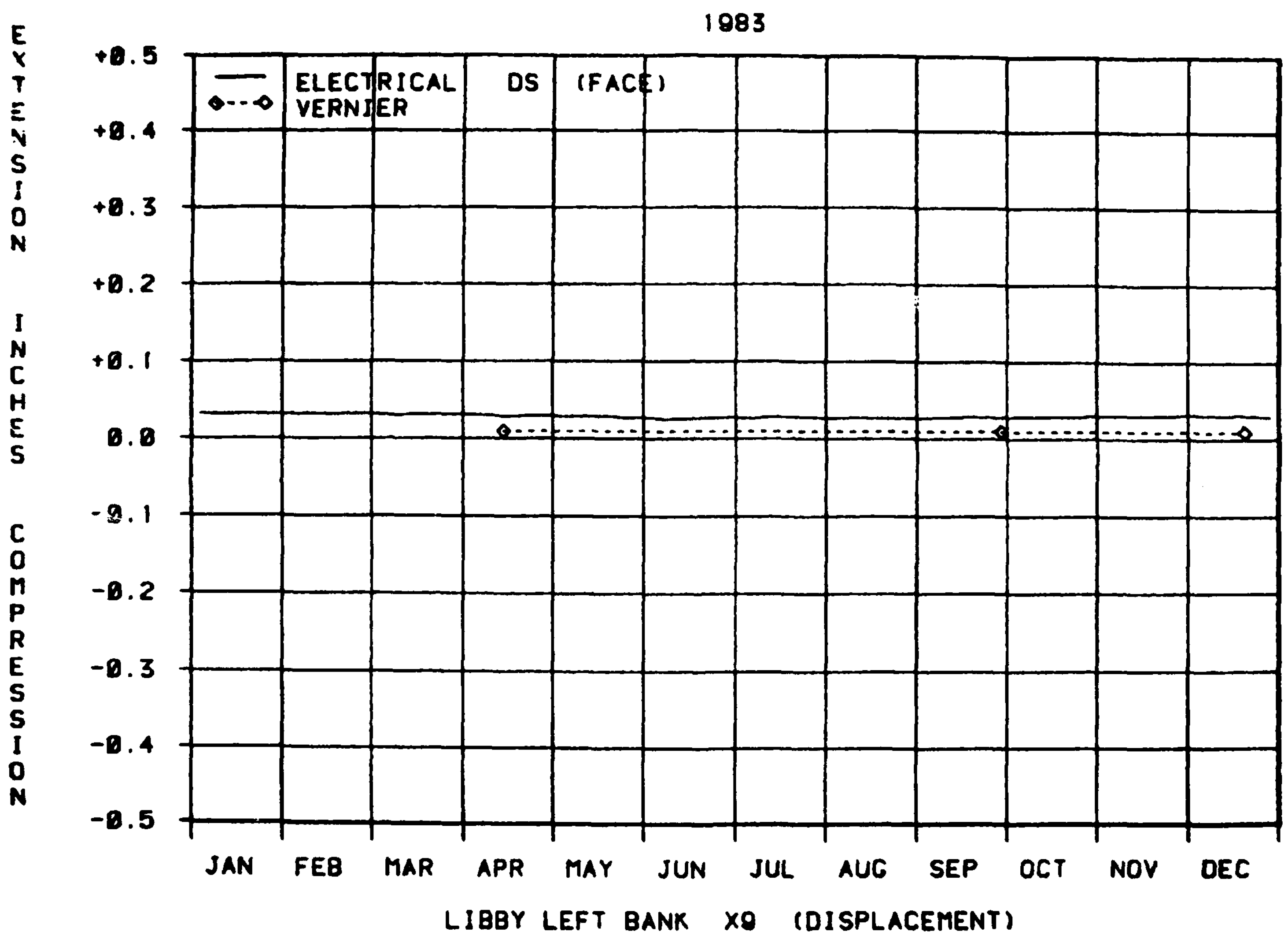

ELECTRICAL C (FACE)
VERNIER
+0.5
+0.4
+0.3
+0.2
+0.1
0.0
-0.1
-0.2
-0.3
-0.4
-0.5
EXTENSION INCHES COMPRESSION
1978
1979
1980
1981
1982
LIBBY LEFT BANK X8 (DISPLACEMENT)

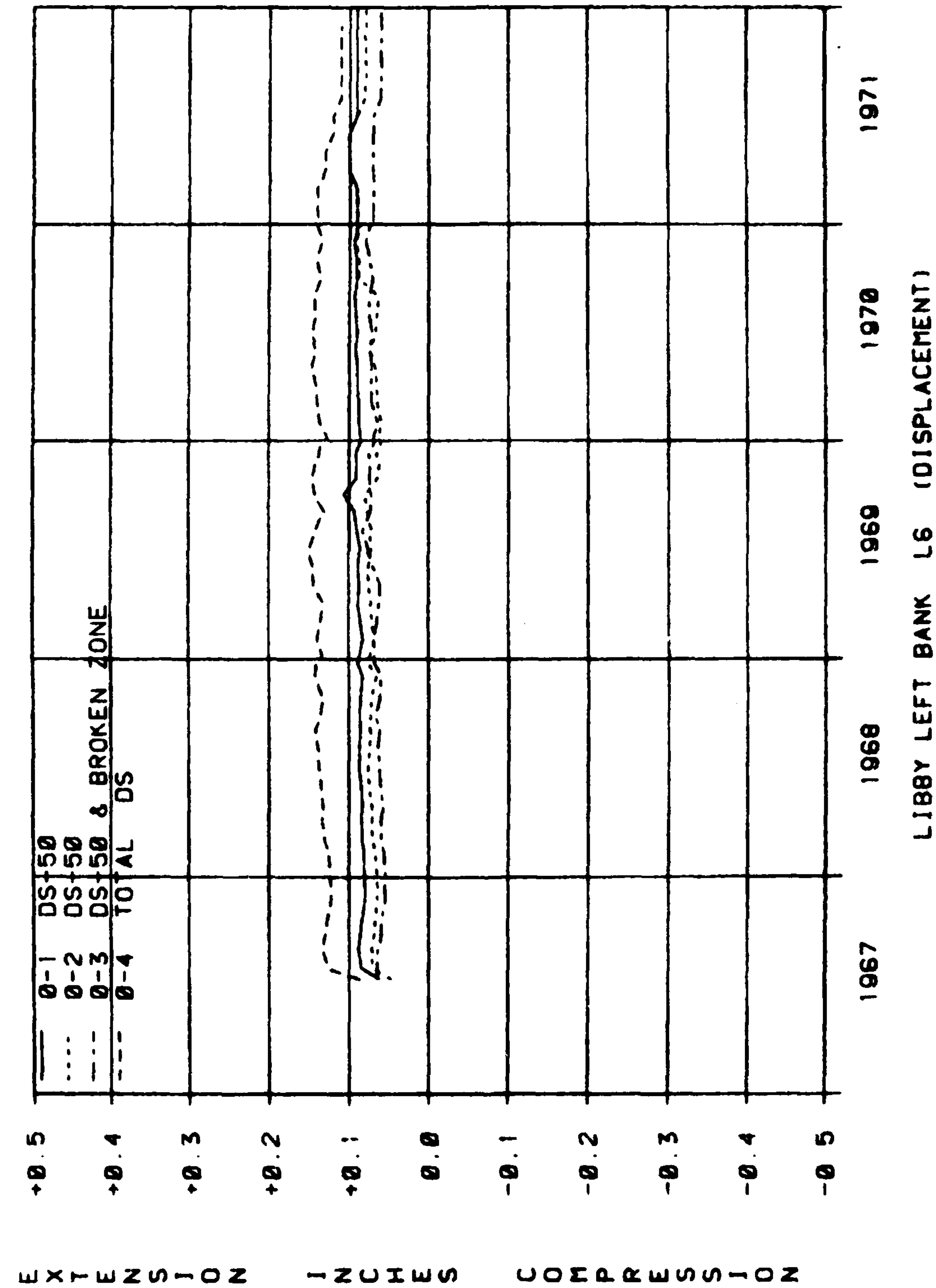

1983
ELECTRICAL
VERNIER
C (FACE
JAN FEB MAR APR MAY JUN JUL AUG SEP OCT NOV DEC
LIBBY LEFT BANK X8 (DISPLACEMENT)
+0.5
+0.4
+0.3
+0.2
+0.1
0.0
-0.1
-0.2
-0.3
-0.4
-0.5
EXTENSION INCHES COMPRESSION



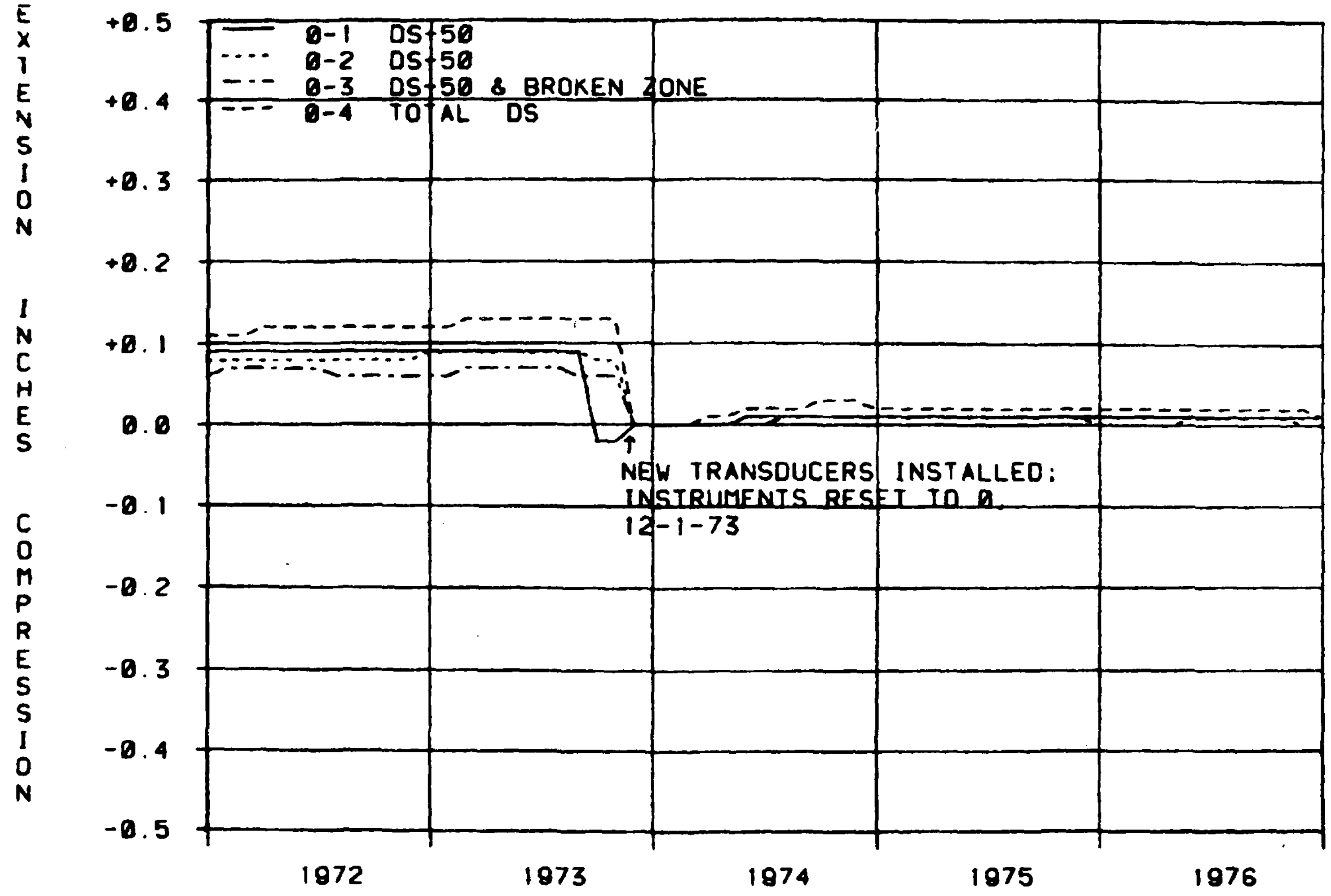
ELECTRICAL DS (FACE)
VERNIER
+0.5
+0.4
+0.3
+0.2
+0.1
0.0
-0.1
-0.2
-0.3
-0.4
-0.5
EXTENSION INCHES COMPRESSION
1973
1974
1975
1976
1977
LIBBY LEFT BANK X9 (DISPLACEMENT)


ELECTRICAL DS (FADE)
VERNIER
LIBBY LEFT BANK X9 (DISPLACEMENT)
1978
1979
1980
1981
1982
+0.5
+0.4
+0.3
+0.2
+0.1
0.0
-0.1
-0.2
-0.3
-0.4
-0.5
EXTENSION INCHES COMPRESSION

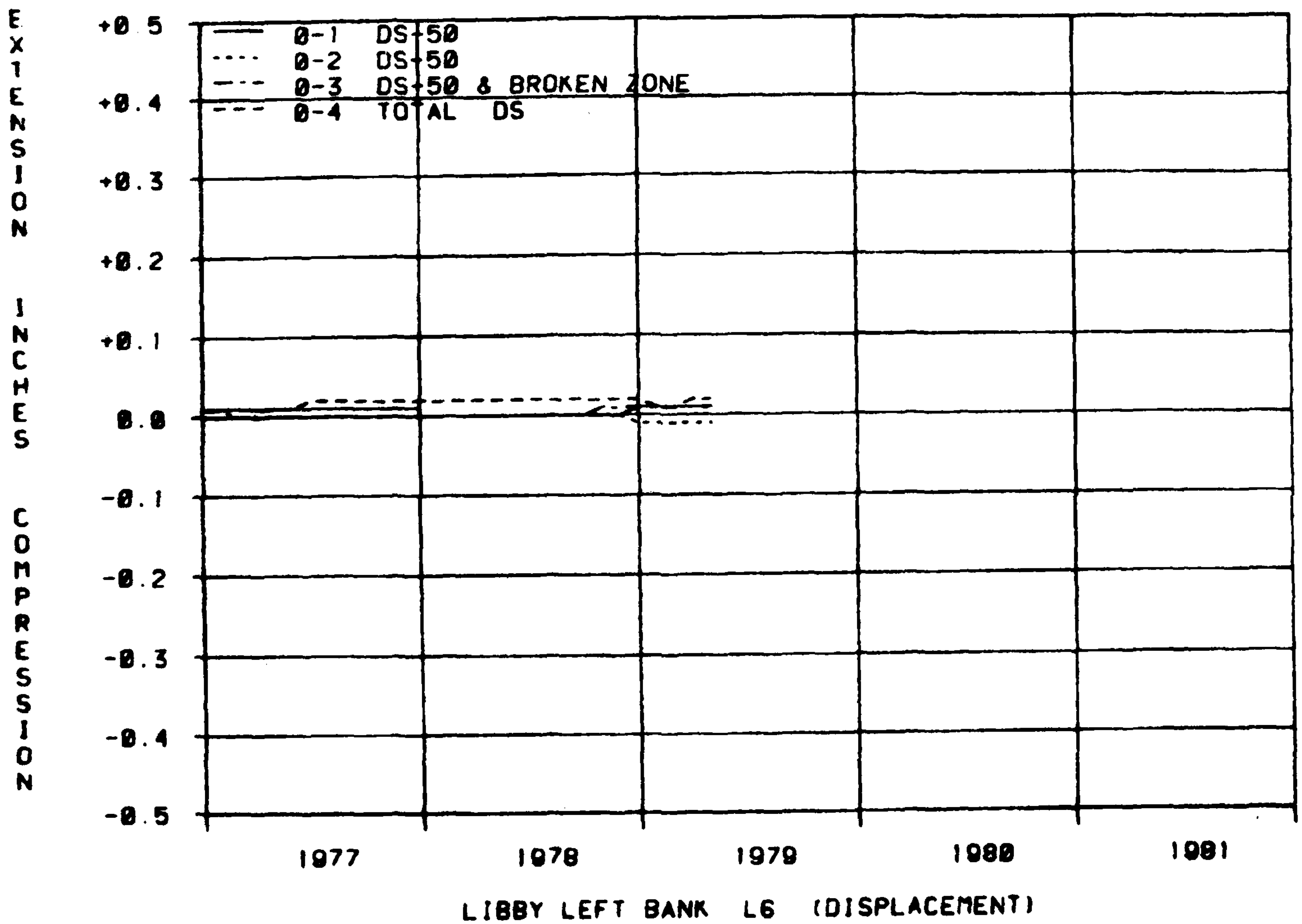

1983
ELECTRICAL
VERNIER
DS (FACE)
EXTENSION INCHES COMPRESSION
+0.5
+0.4
+0.3
+0.2
+0.1
0.0
-0.1
-0.2
-0.3
-0.4
-0.5
JAN FEB MAR APR MAY JUN JUL AUG SEP OCT NOV DEC
LIBBY LEFT BANK X9 (DISPLACEMENT)

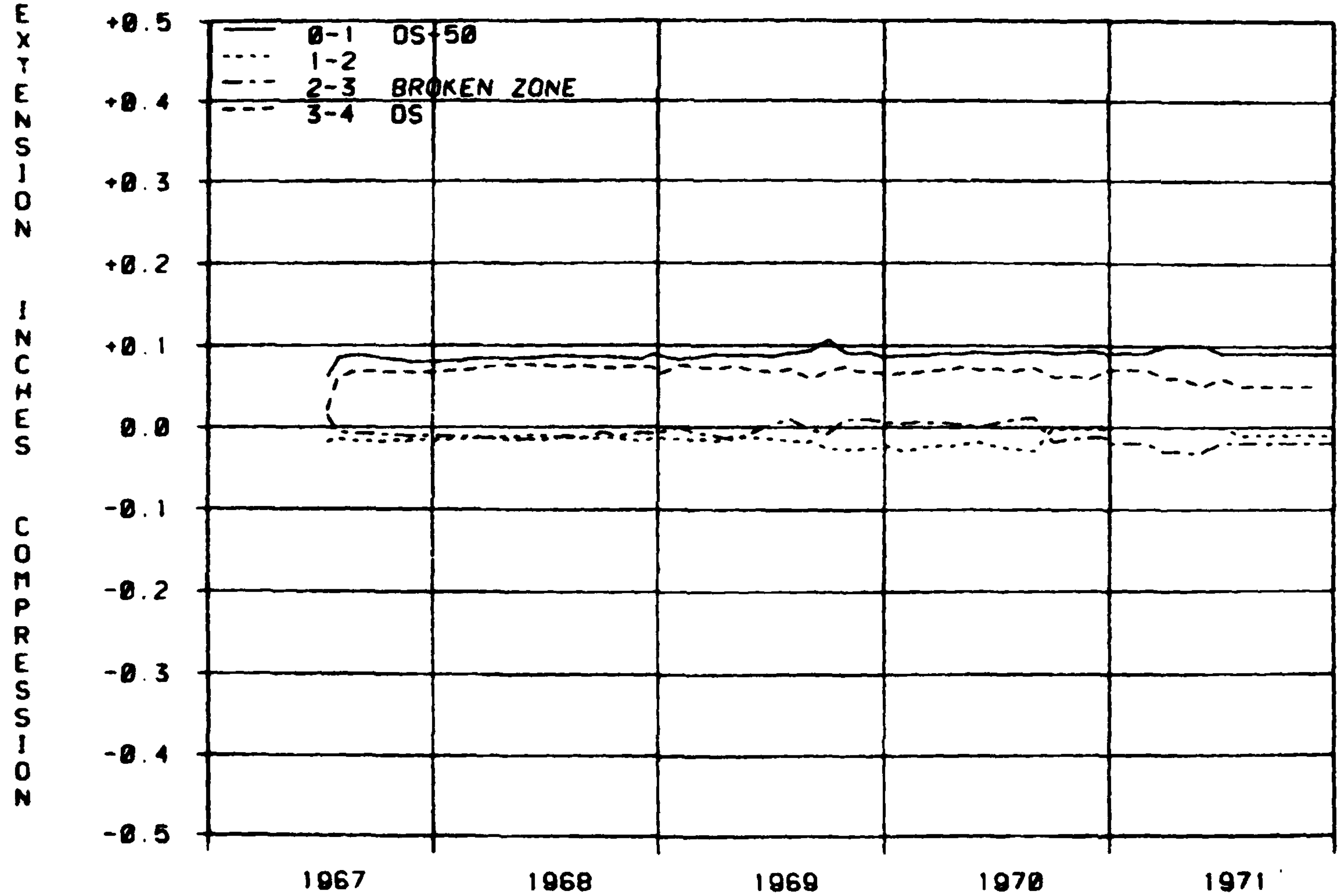


0-1 DS-50
0-2 DS-50
0-3 DS-50 & BROKEN ZONE
0-4 TOTAL DS
+0.5
+0.4
+0.3
+0.2
+0.1
0.0
-0.1
-0.2
-0.3
-0.4
-0.5
EXTENSION INCHES COMPRESSION
1967
1968
1969
1970
1971
LIBBY LEFT BANK L6 (DISPLACEMENT)

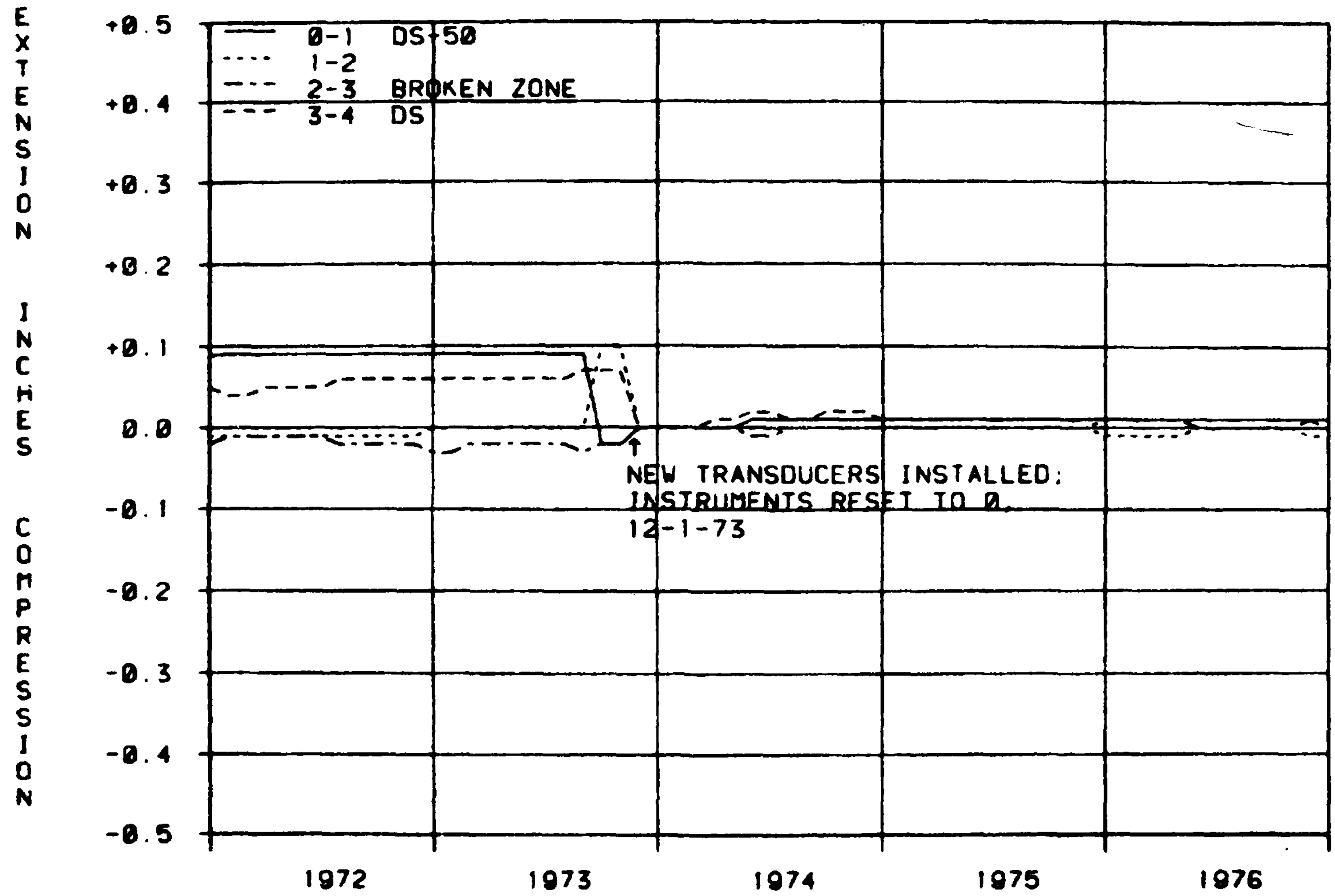


LIBBY LEFT BANK L6 (DISPLACEMENT)

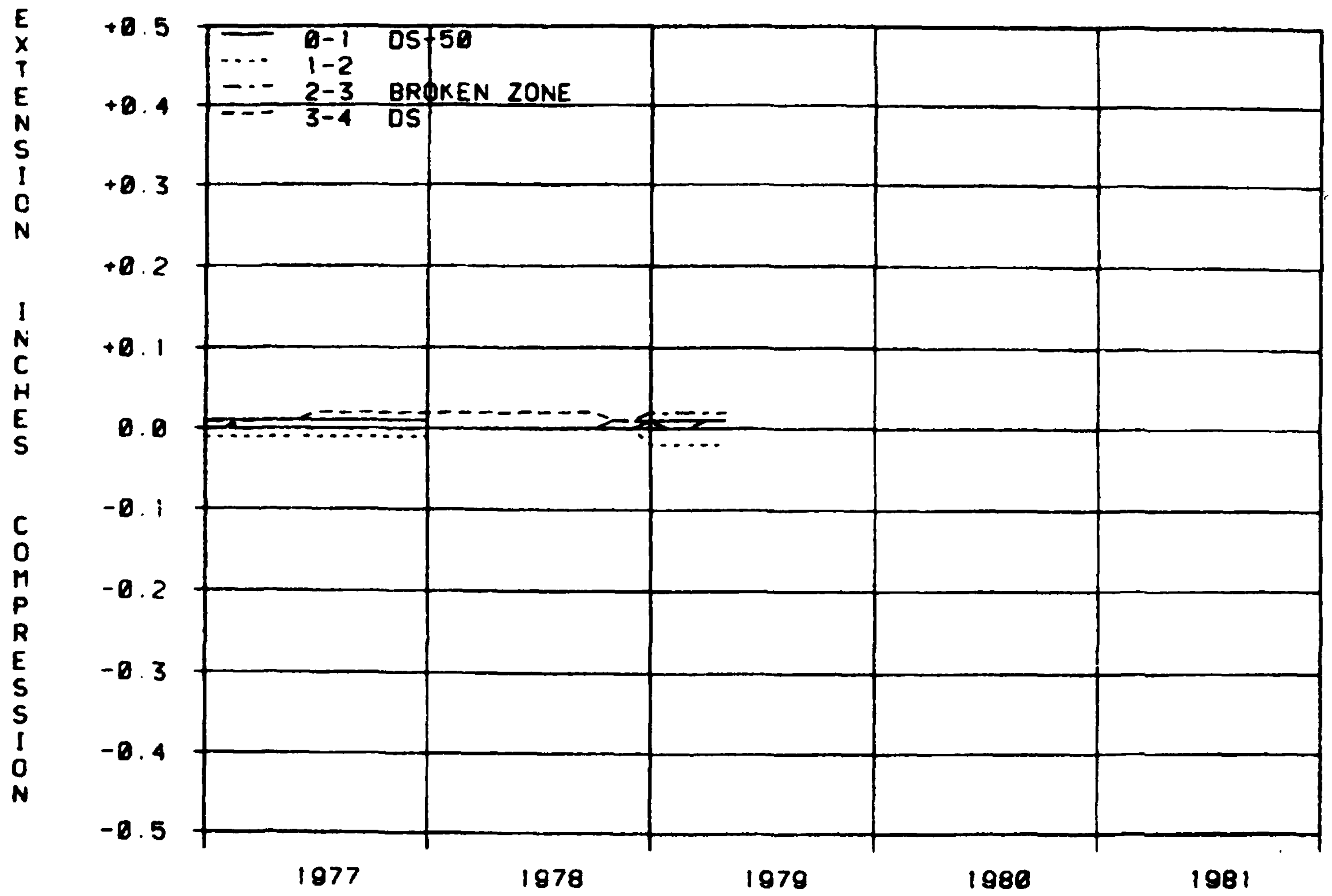

EXTENSION INCHES COMPRESSION
+0.5
+0.4
+0.3
+0.2
+0.1
0.0
-0.1
-0.2
-0.3
-0.4
-0.5
0-1 DS-50
0-2 DS-50
0-3 DS-50 & BROKEN ZONE
0-4 TOTAL DS
1977
1978
1979
1980
1981
LIBBY LEFT BANK L6 (DISPLACEMENT)



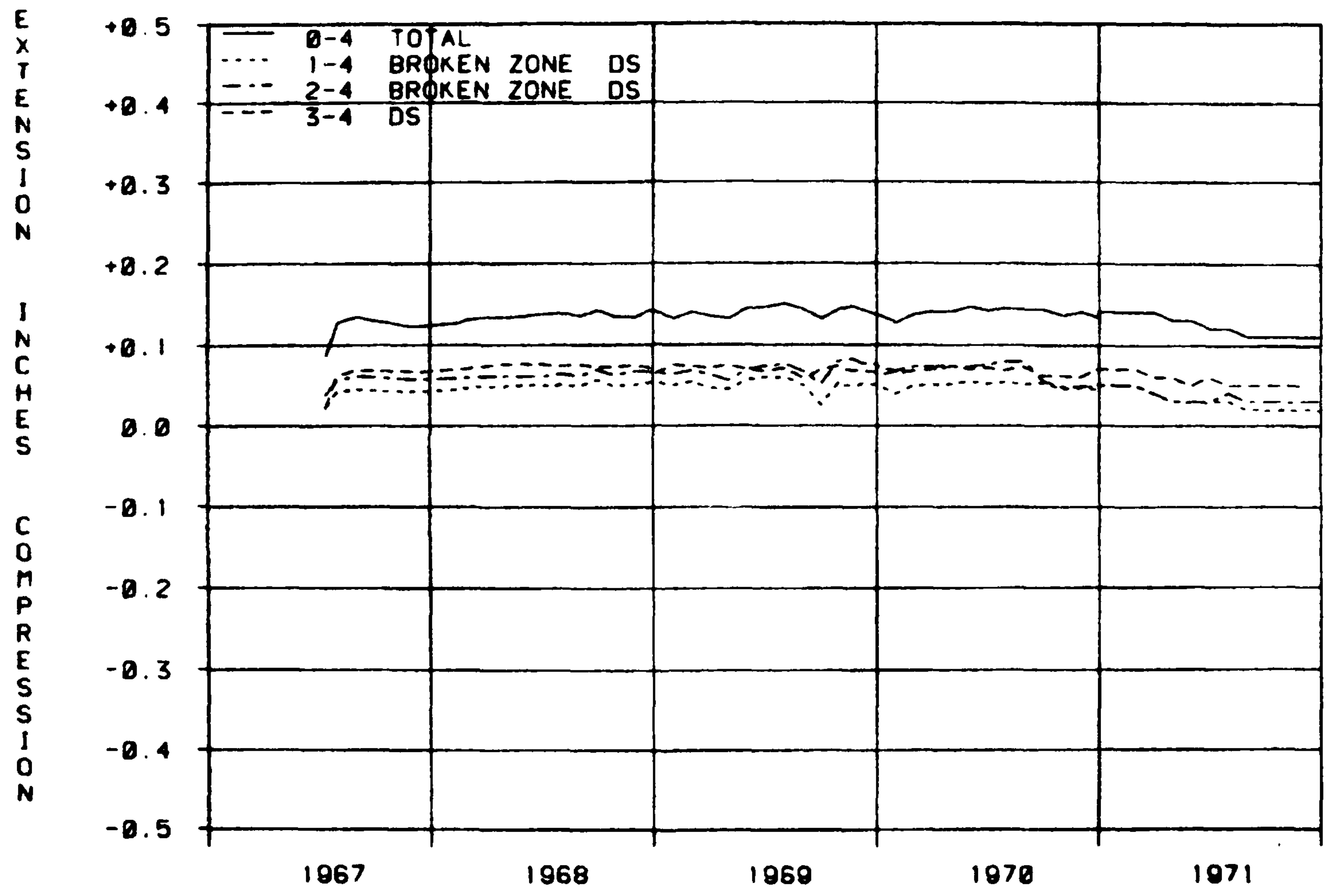
LIBBY LEFT BANK L6 (DELTA DISPLACEMENT)



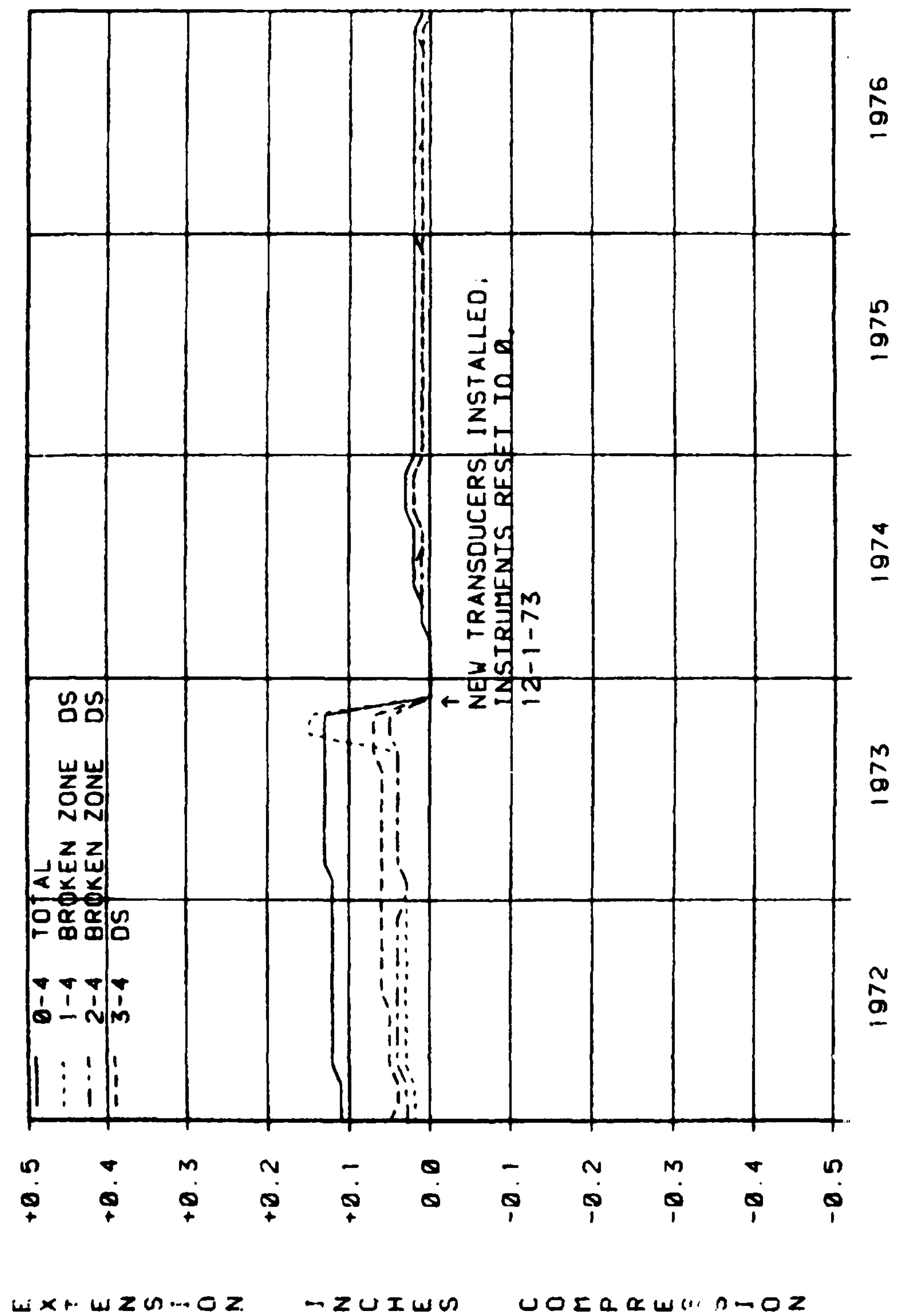
LIBBY LEFT BANK L6 (DELTA DISPLACEMENT)



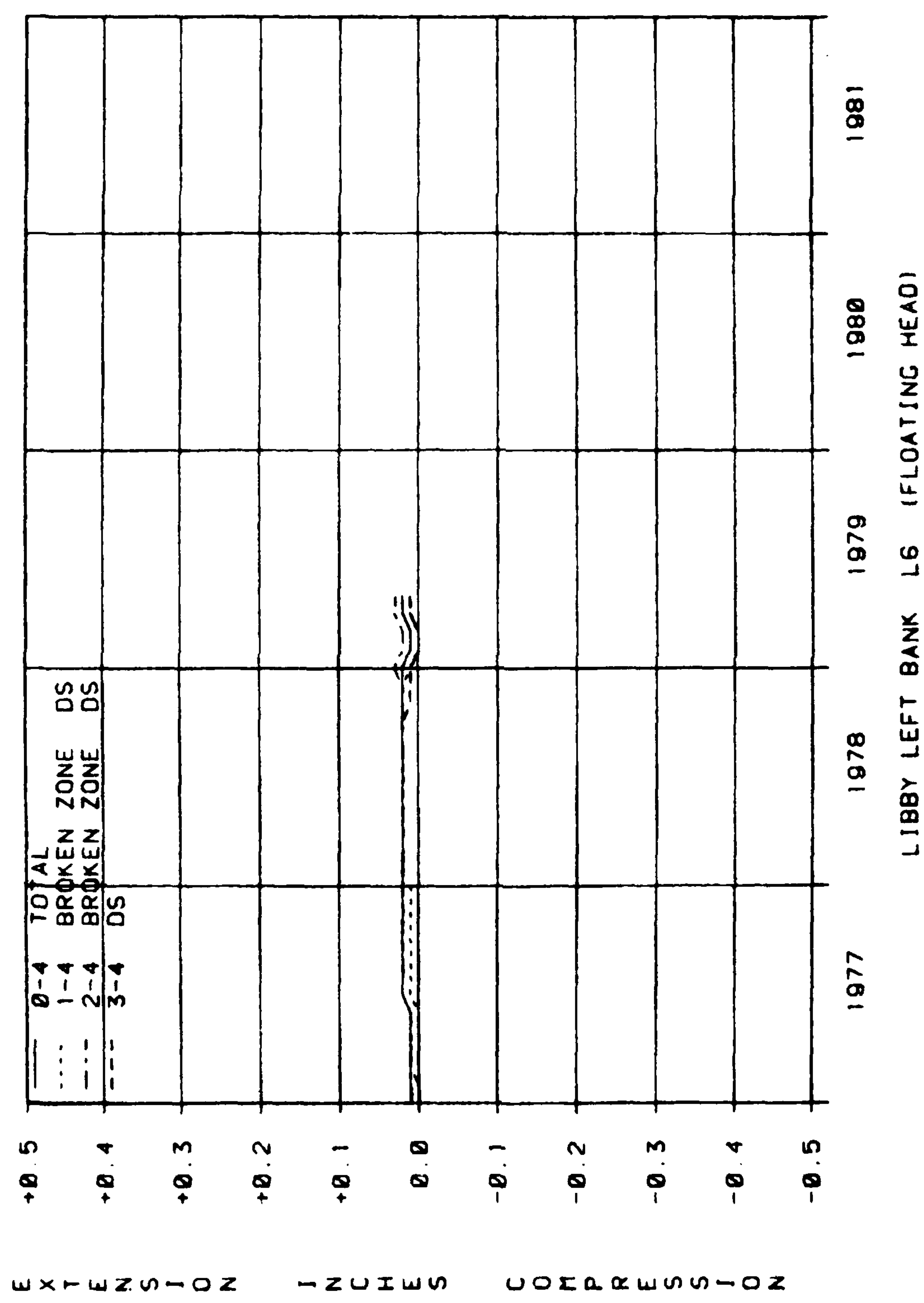
LIBBY LEFT BANK L6 (DELTA DISPLACEMENT)



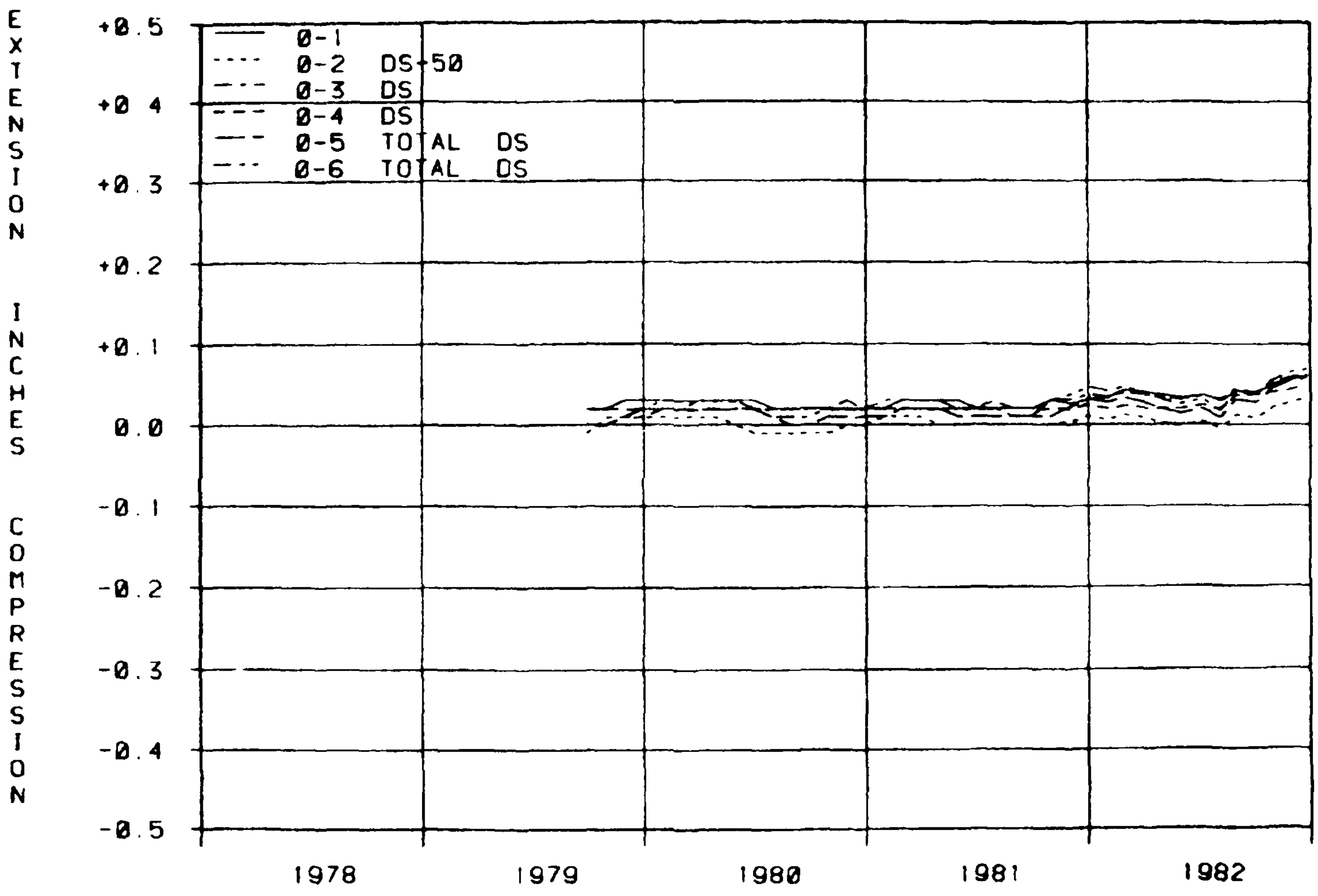
LIBBY LEFT BANK L6 (FLOATING HEAD)



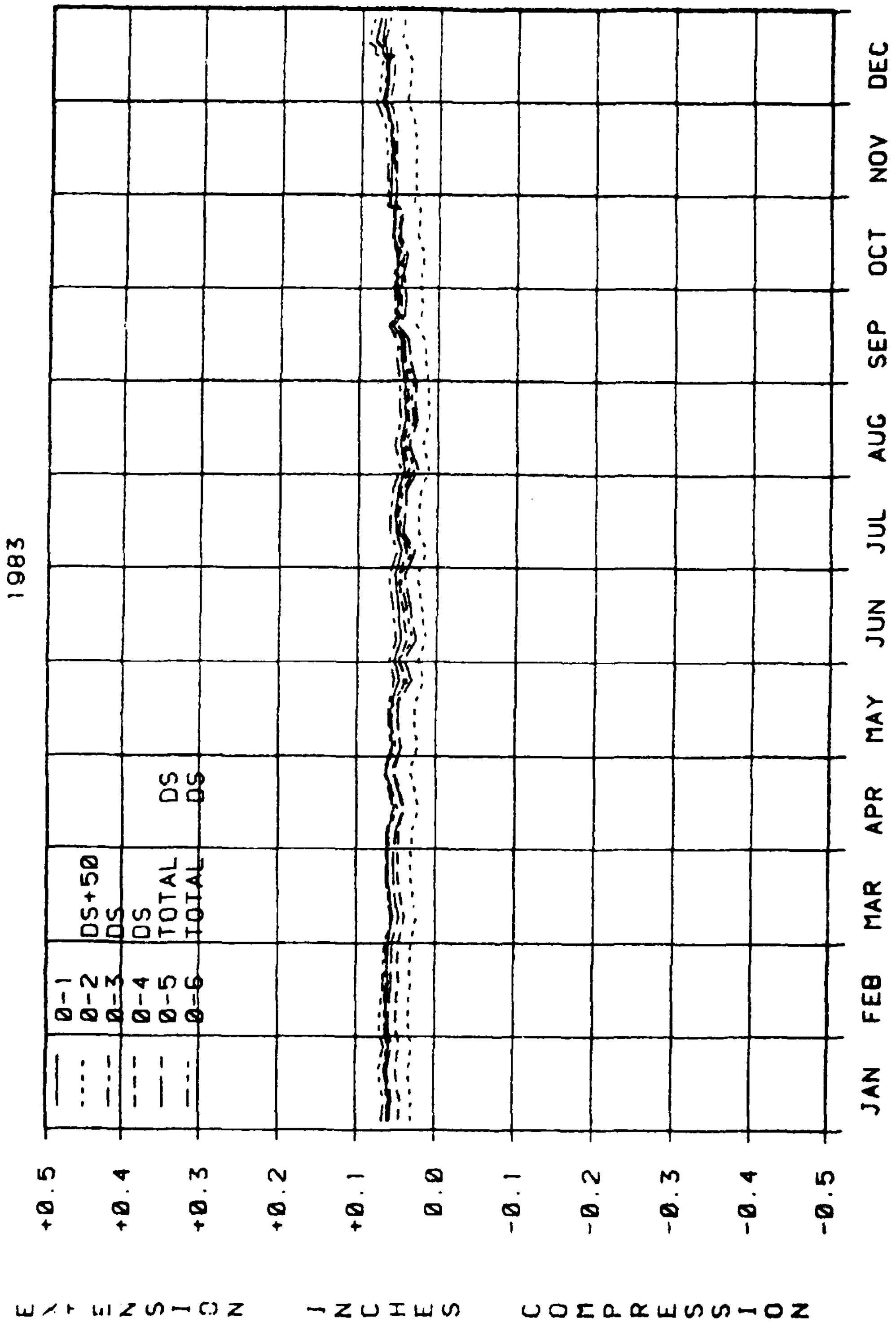
LIBBY LEFT BANK L6 (FLOATING HEAD)



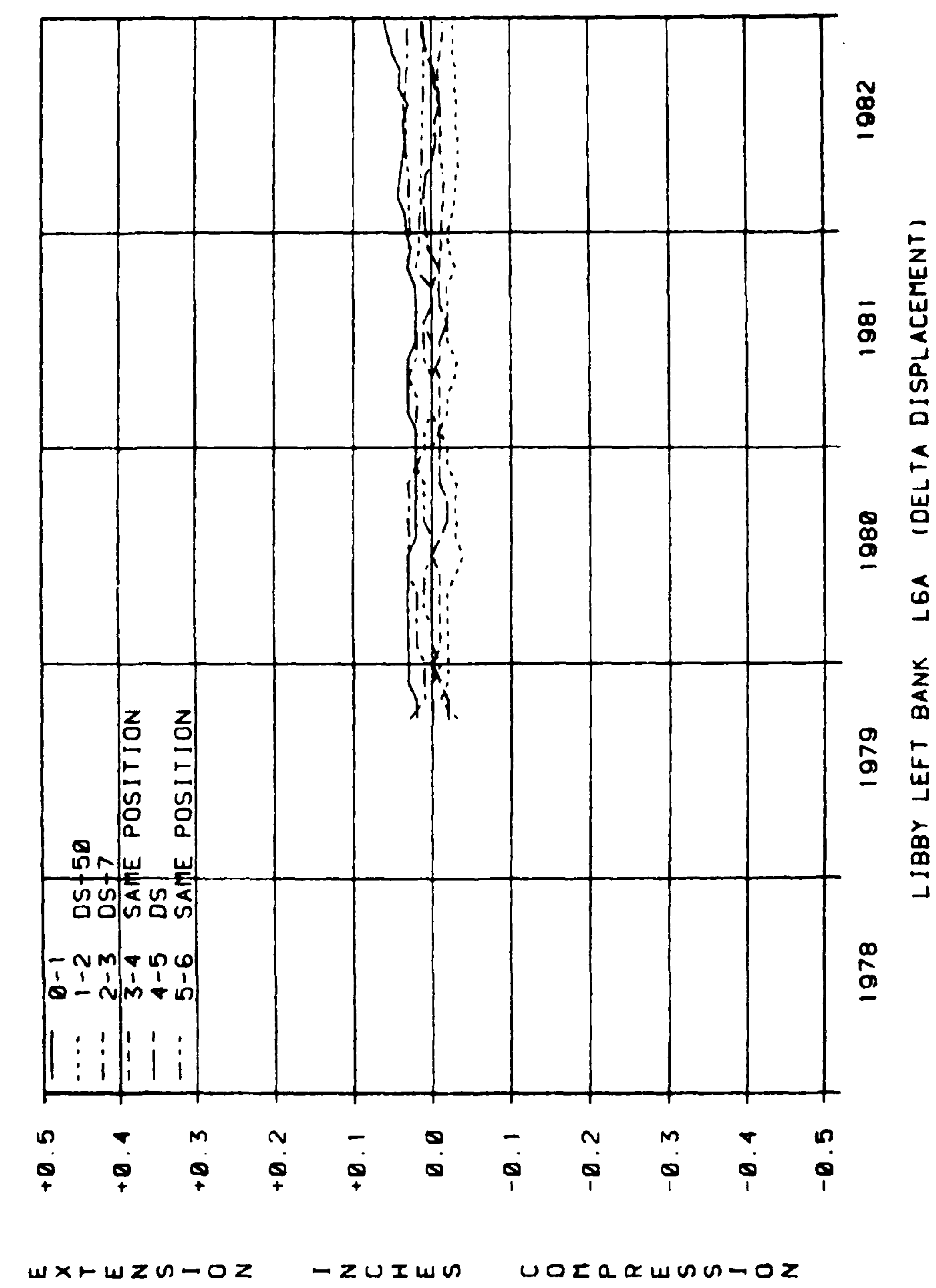
Ø-4 TOTAL
1-4 BROKEN ZONE DS
2-4 BROKEN ZONE DS
3-4 DS
+Ø.5
+Ø.4
+Ø.3
+Ø.2
+Ø.1
Ø.Ø
-Ø.1
-Ø.2
-Ø.3
-Ø.4
-Ø.5
EXTENSION
INCHES
COMPRESSION
1977
1978
1979
1980
1981
LIBBY LEFT BANK L6 (FLOATING HEAD)



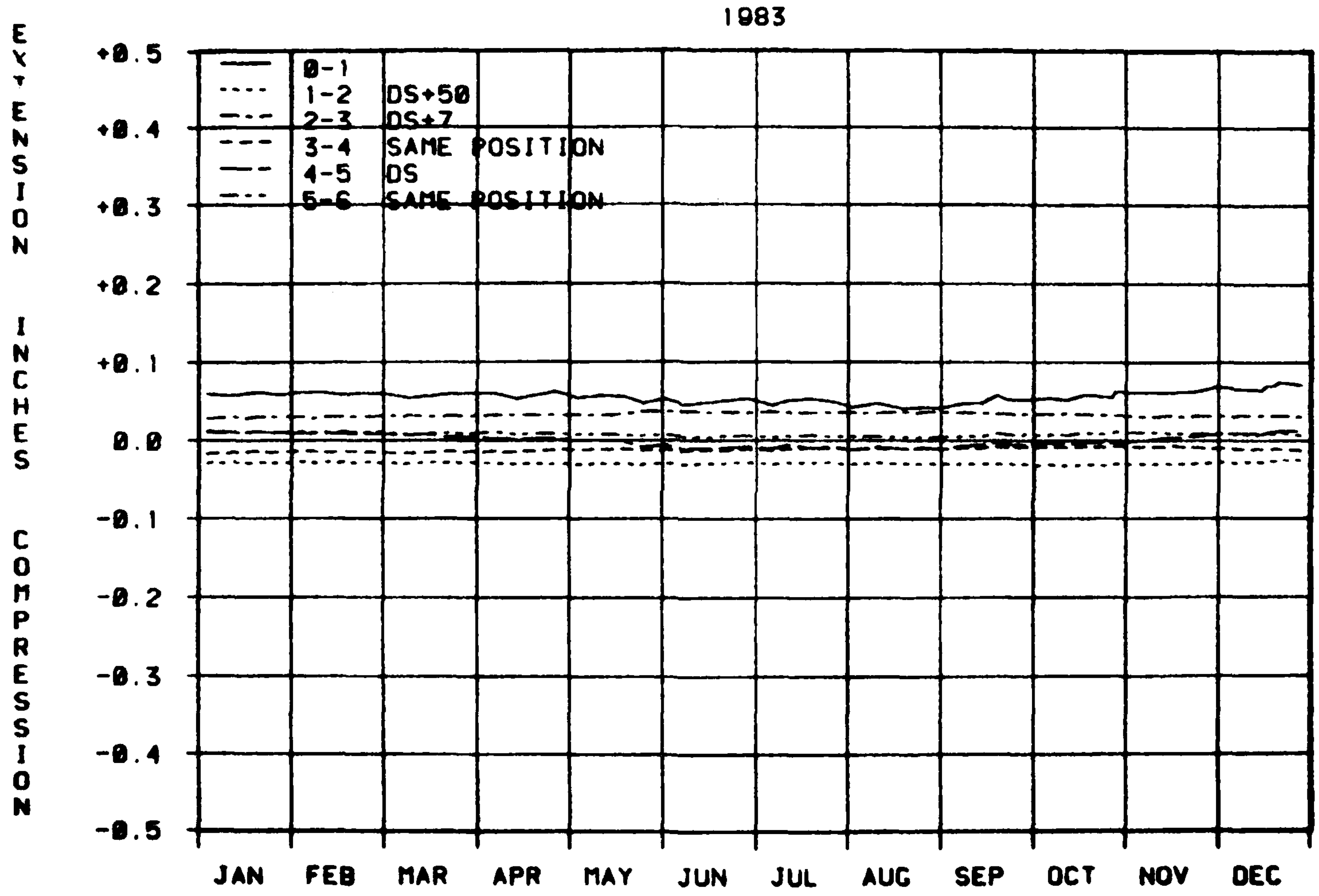
LIBBY LEFT BANK L6A (DISPLACEMENT)



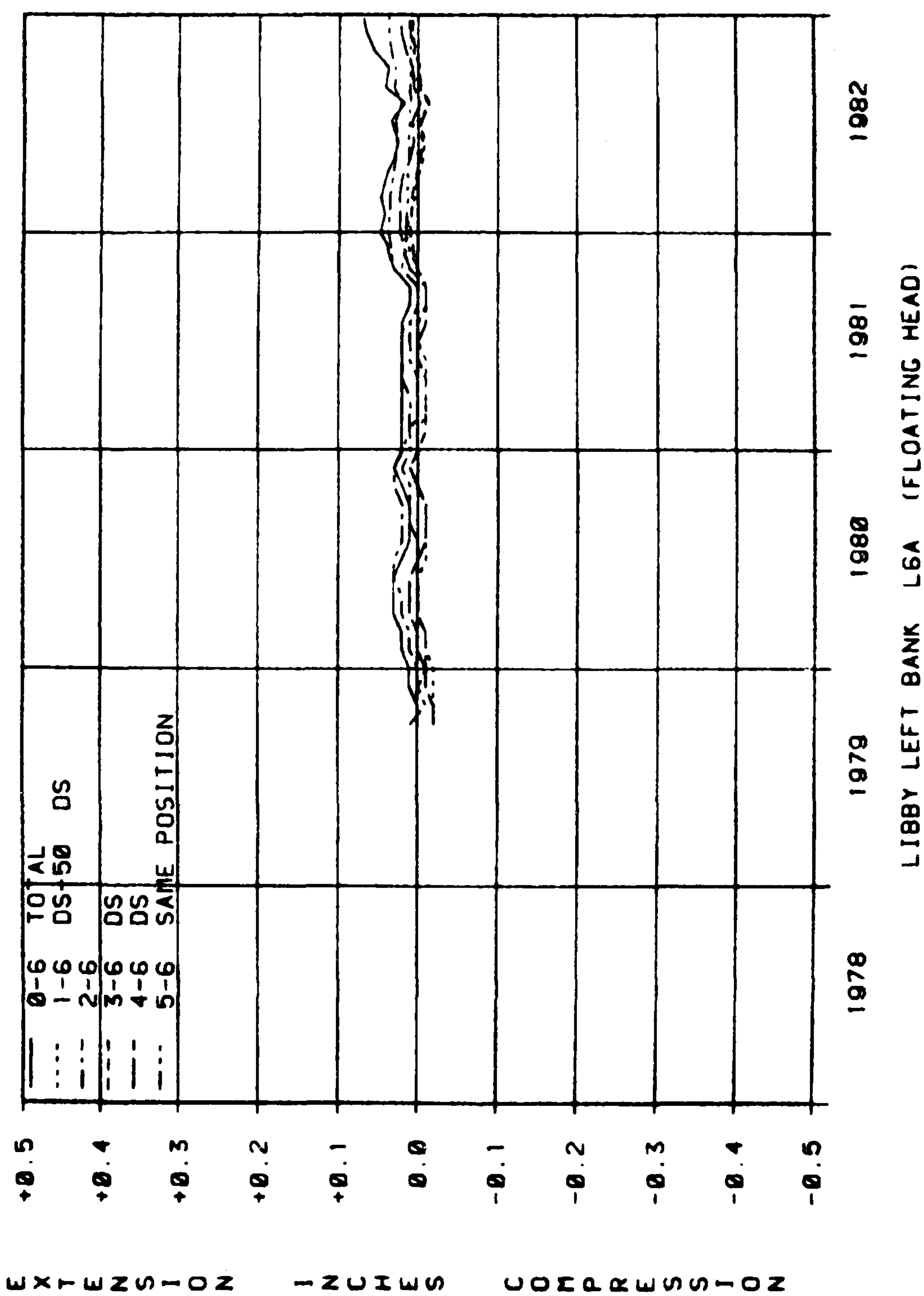
LIBBY LEFT BANK L6A (DISPLACEMENT)

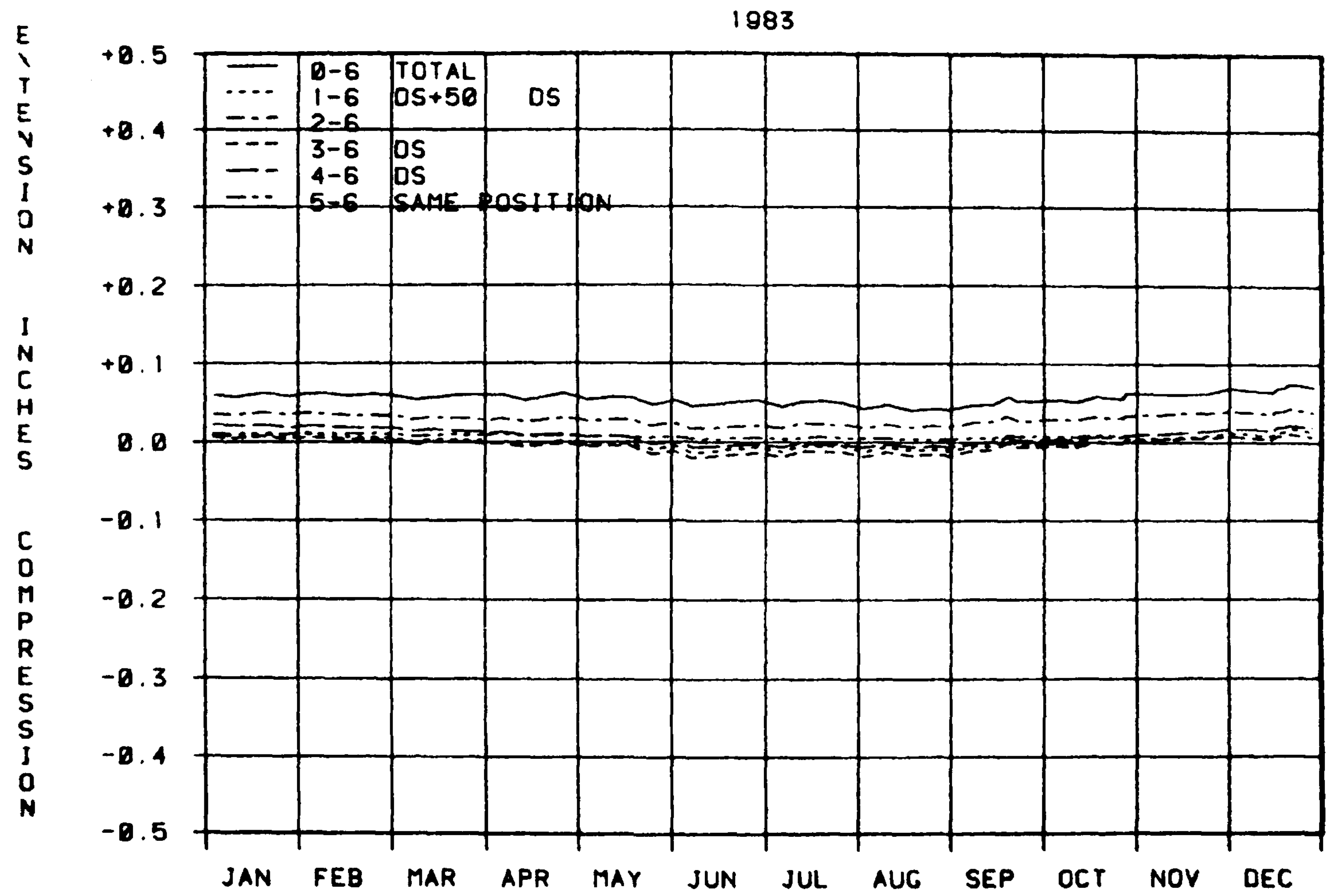


LIBBY LEFT BANK L6A (DELTA DISPLACEMENT)
0-1
1-2 DS-50
2-3 DS-7
3-4 SAME POSITION
4-5 DS
5-6 SAME POSITION
1978
1979
1980
1981
1982
+0.5
+0.4
+0.3
+0.2
+0.1
0.0
-0.1
-0.2
-0.3
-0.4
-0.5
EXTENSION
INCHES
COMPRESSION

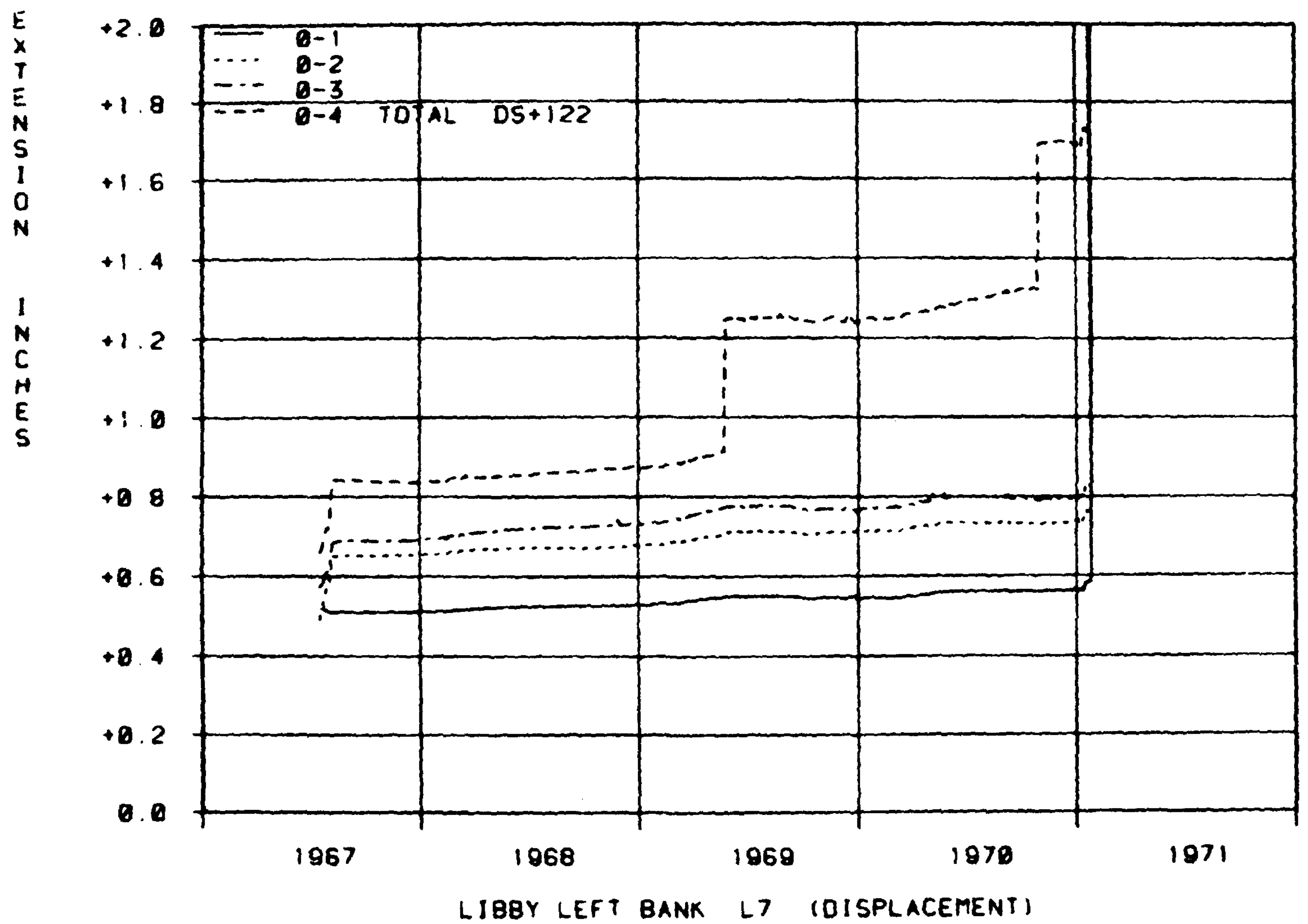


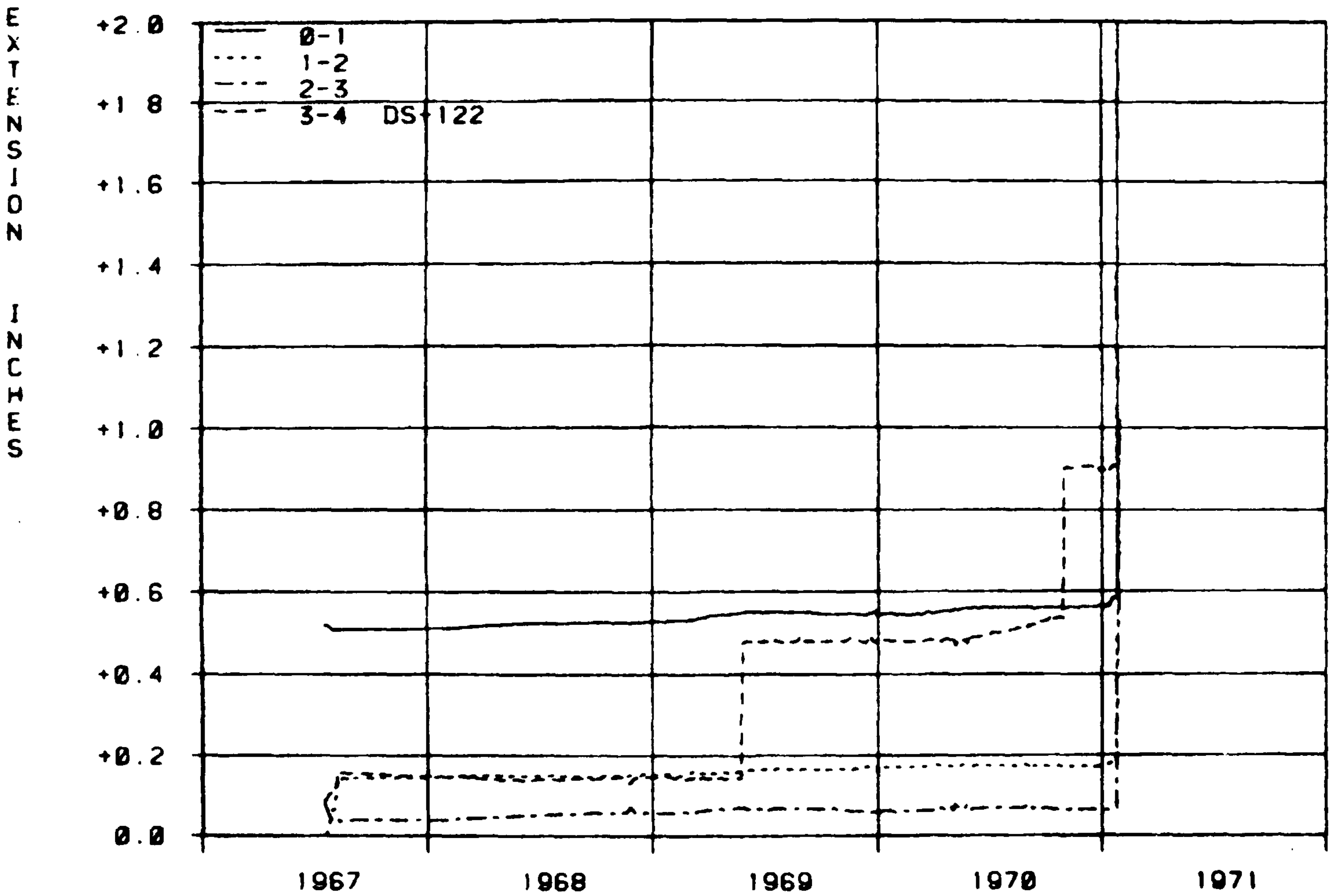
LIBBY LEFT BANK L6A (DELTA DISPLACEMENT)


0-6 TOTAL
1-6 DS-50 DS
2-6
3-6 DS
4-6 DS
5-6 SAME POSITION
+0.5
+0.4
+0.3
+0.2
+0.1
0.0
-0.1
-0.2
-0.3
-0.4
-0.5
EXTENSION INCHES COMPRESSION
1978
1979
1980
1981
1982
LIBBY LEFT BANK L6A (FLOATING HEAD)

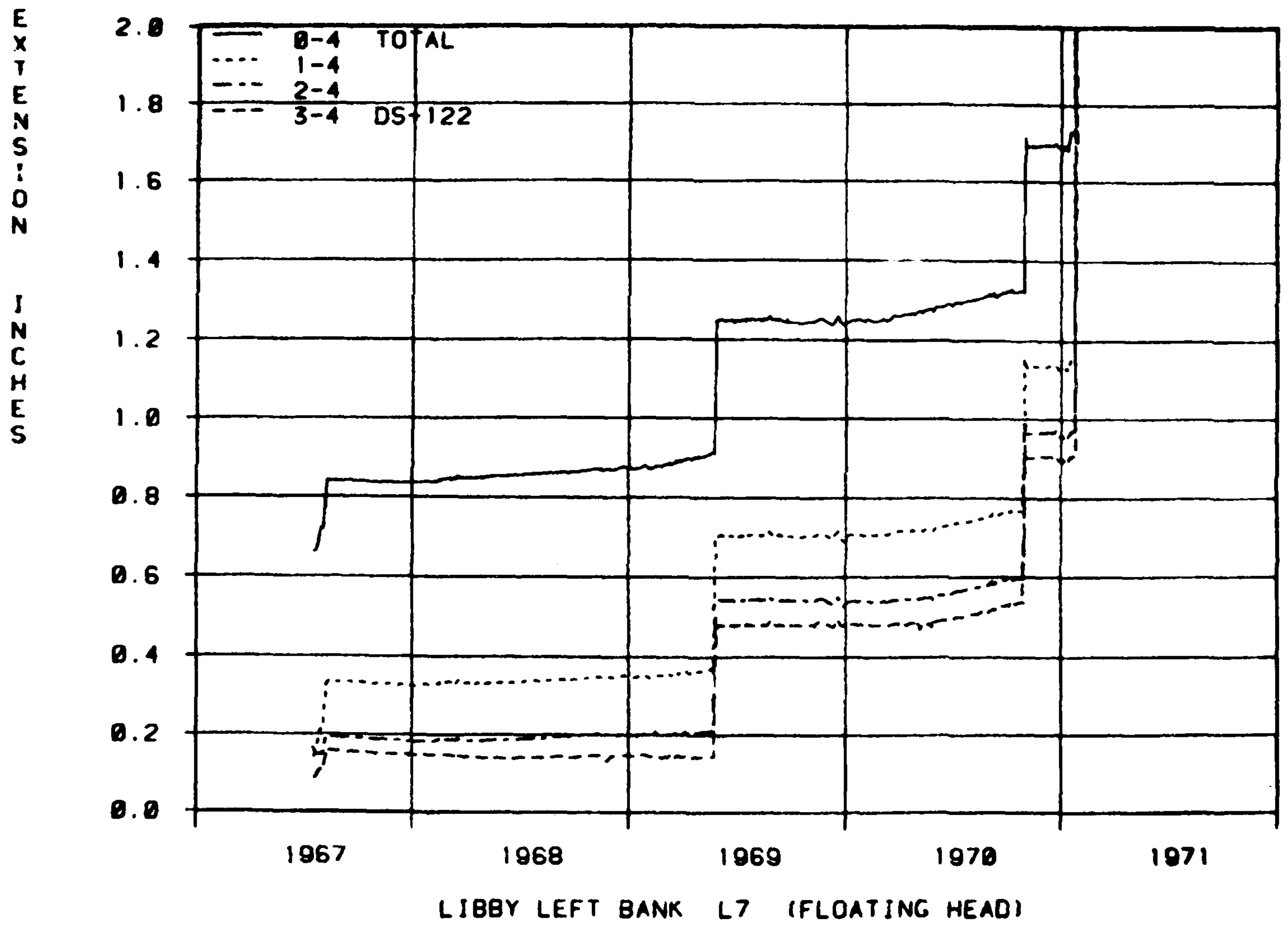


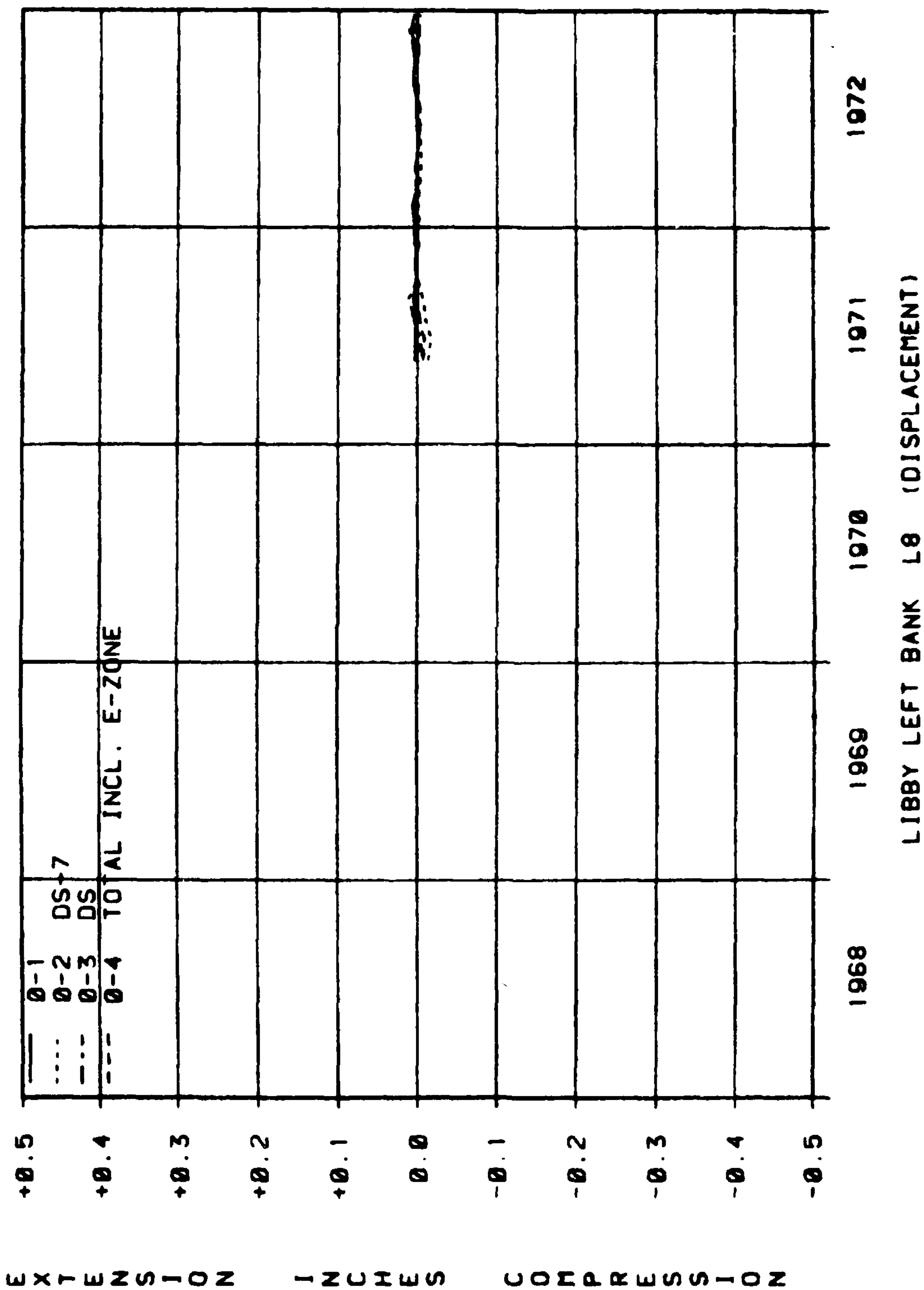
LIBBY LEFT BANK L6A (FLOATING HEAD)


EXTENSION INCHES
+2.0
+1.8
+1.6
+1.4
+1.2
+1.0
+0.8
+0.6
+0.4
+0.2
0.0
0-1
0-2
0-3
0-4 TOTAL DS+122
1967
1968
1969
1970
1971
LIBBY LEFT BANK L7 (DISPLACEMENT)

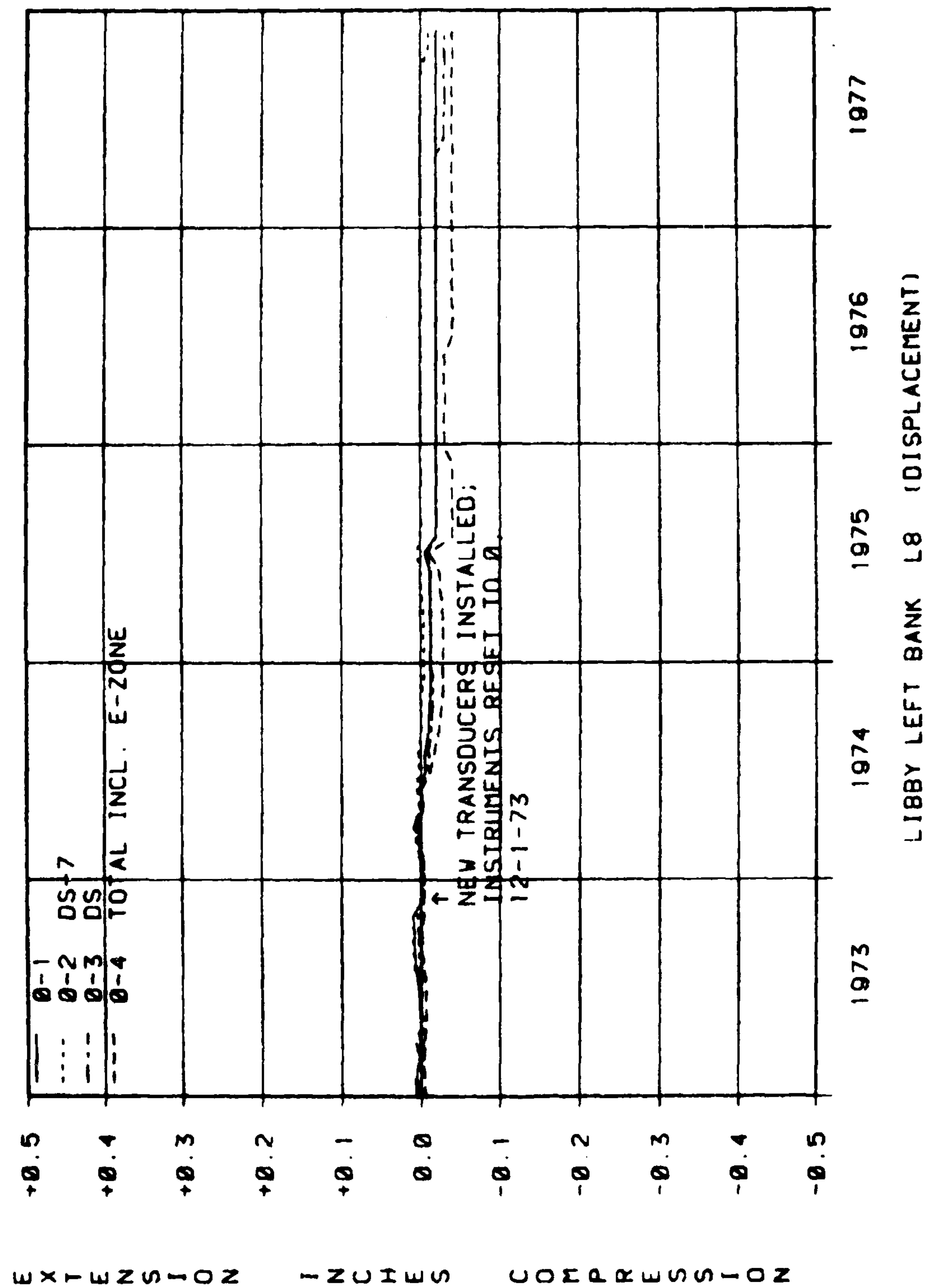


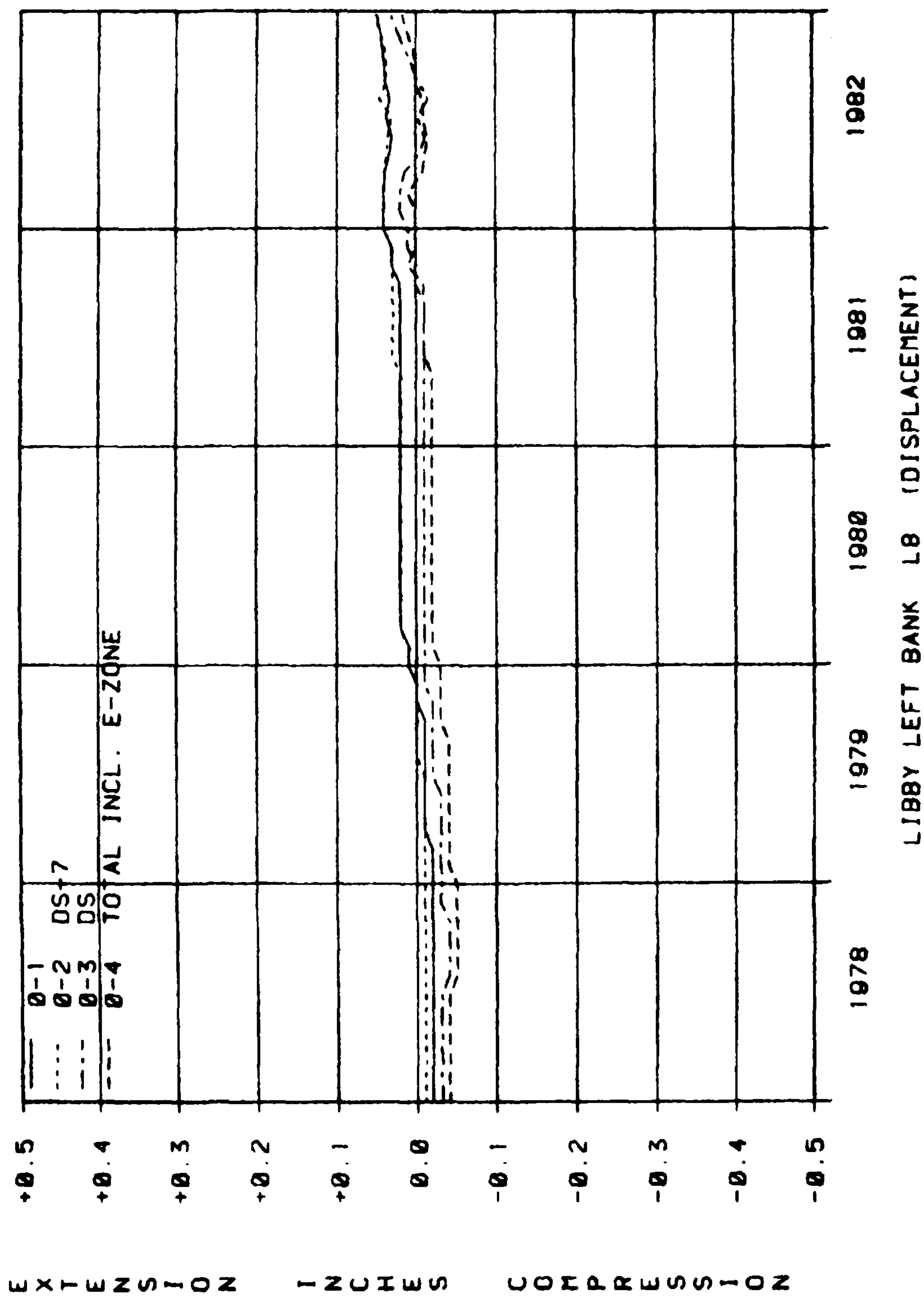
LIBBY LEFT BANK L7 (DELTA DISPLACEMENT)

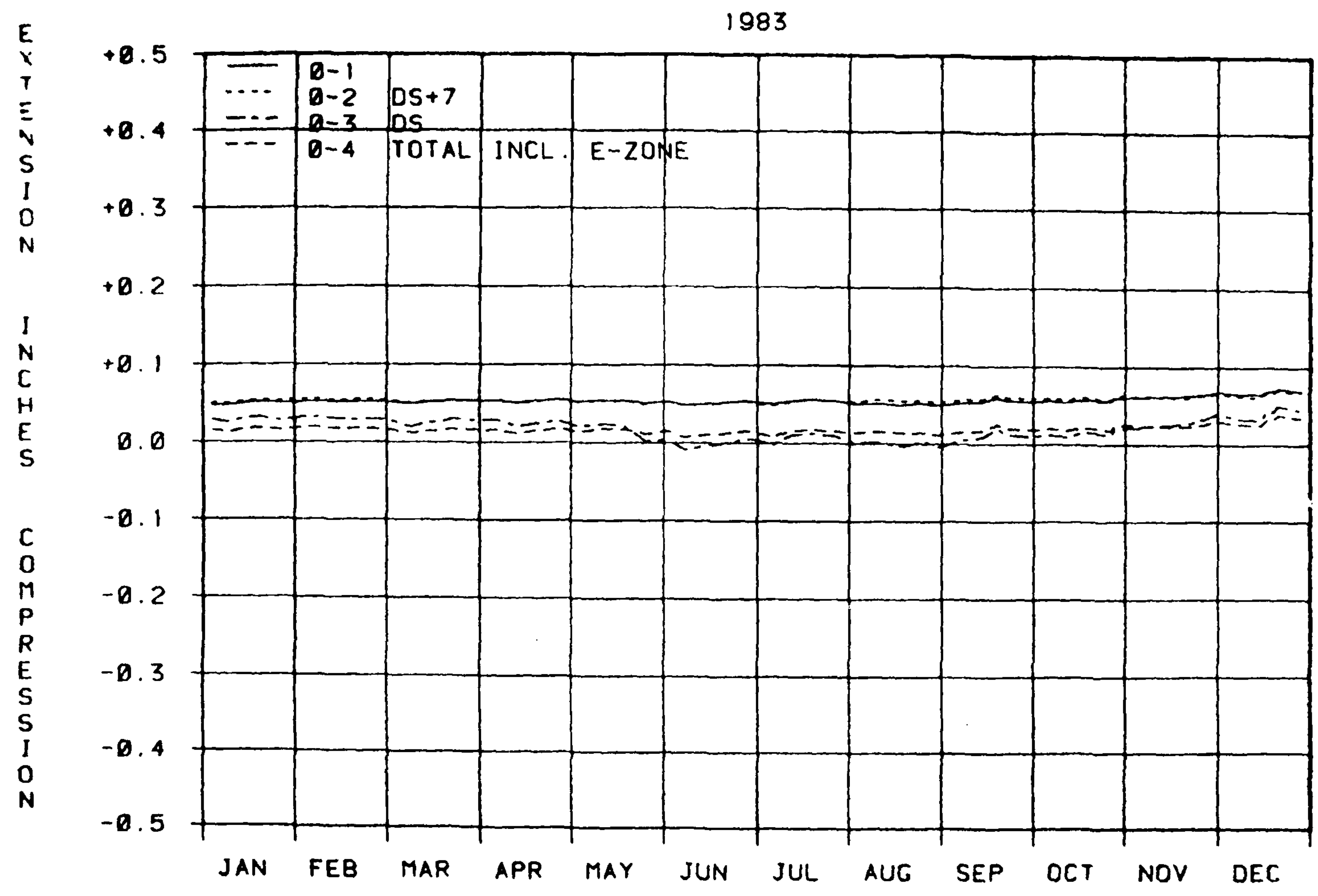

EXTENSION INCHES
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
0-4 TOTAL
1-4
2-4
3-4 DS-122
1967
1968
1969
1970
1971
LIBBY LEFT BANK L7 (FLOATING HEAD)



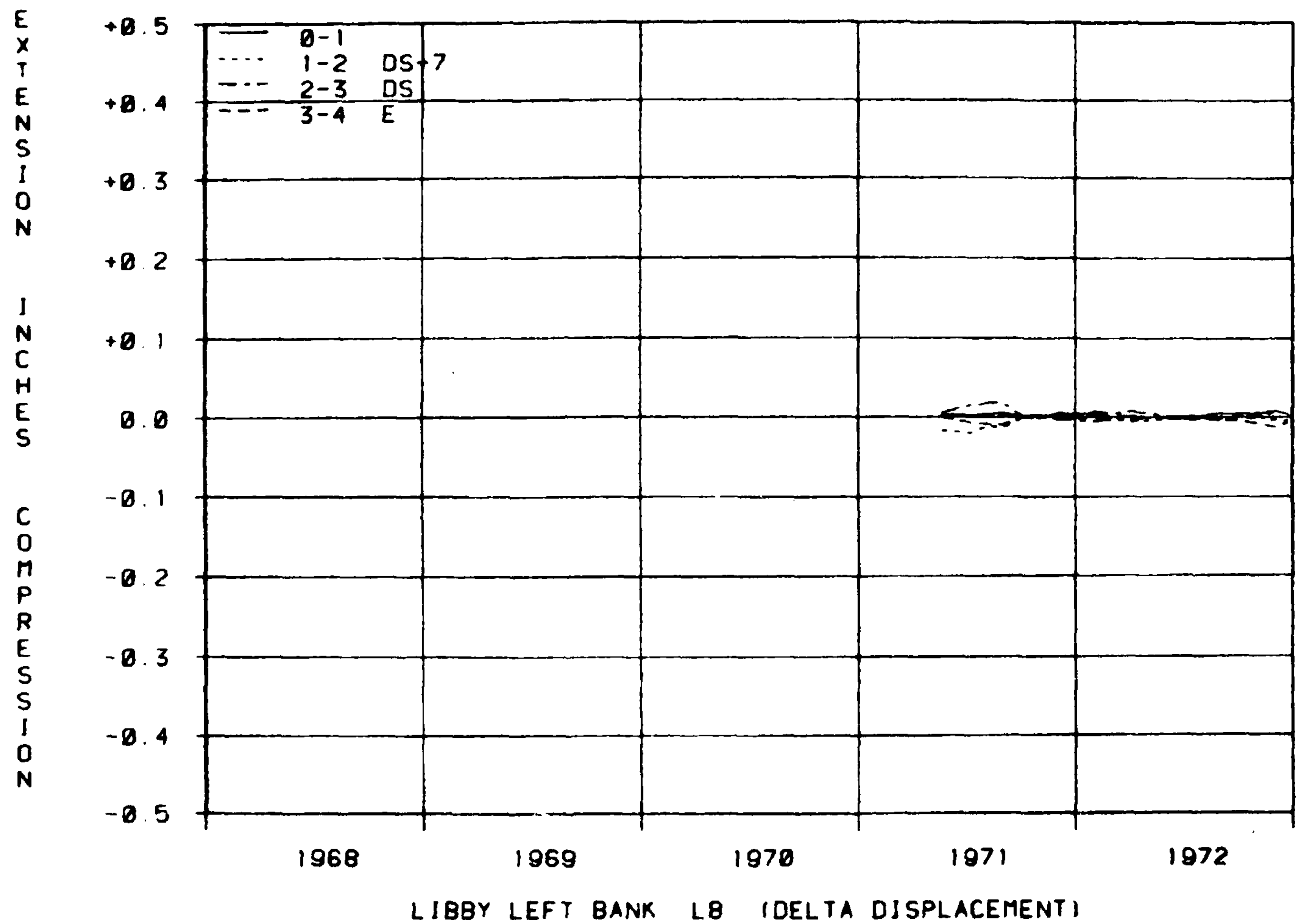
LIBBY LEFT BANK L8 (DISPLACEMENT)
EXTENSION INCHES COMPRESSION
+0.5
+0.4
+0.3
+0.2
+0.1
0.0
-0.1
-0.2
-0.3
-0.4
-0.5
1968
1969
1970
1971
1972
0-1
0-2 DS-7
0-3 DS
0-4 TOTAL INCL. E-ZONE

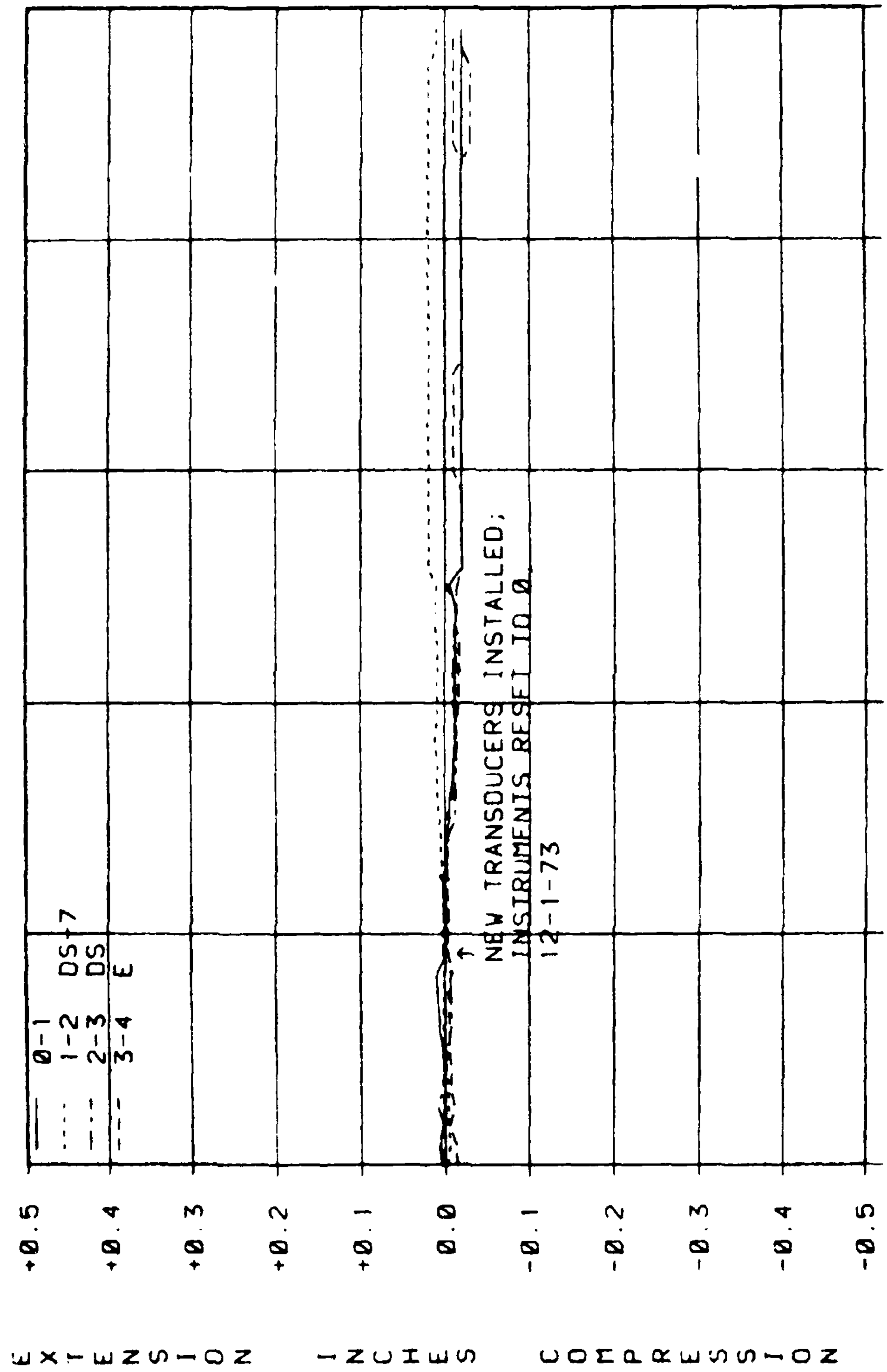

LIBBY LEFT BANK L8 (DISPLACEMENT)
EXTENSION INCHES COMPRESSION
+0.5
+0.4
+0.3
+0.2
+0.1
0.0
-0.1
-0.2
-0.3
-0.4
-0.5
1973
1974
1975
1976
1977
Ø-1
Ø-2 DS-7
Ø-3 DS
Ø-4 TOTAL INCL. E-ZONE
NEW TRANSDUCERS INSTALLED;
INSTRUMENTS RESET TO Ø
12-1-73


Ø-1
Ø-2 DS-7
Ø-3 DS
Ø-4 TOTAL INCL. E-ZONE
+Ø.5
+Ø.4
+Ø.3
+Ø.2
+Ø.1
Ø.Ø
-Ø.1
-Ø.2
-Ø.3
-Ø.4
-Ø.5
EXTENSION INCHES COMPRESSION
1978
1979
1980
1981
1982
LIBBY LEFT BANK LB (DISPLACEMENT)

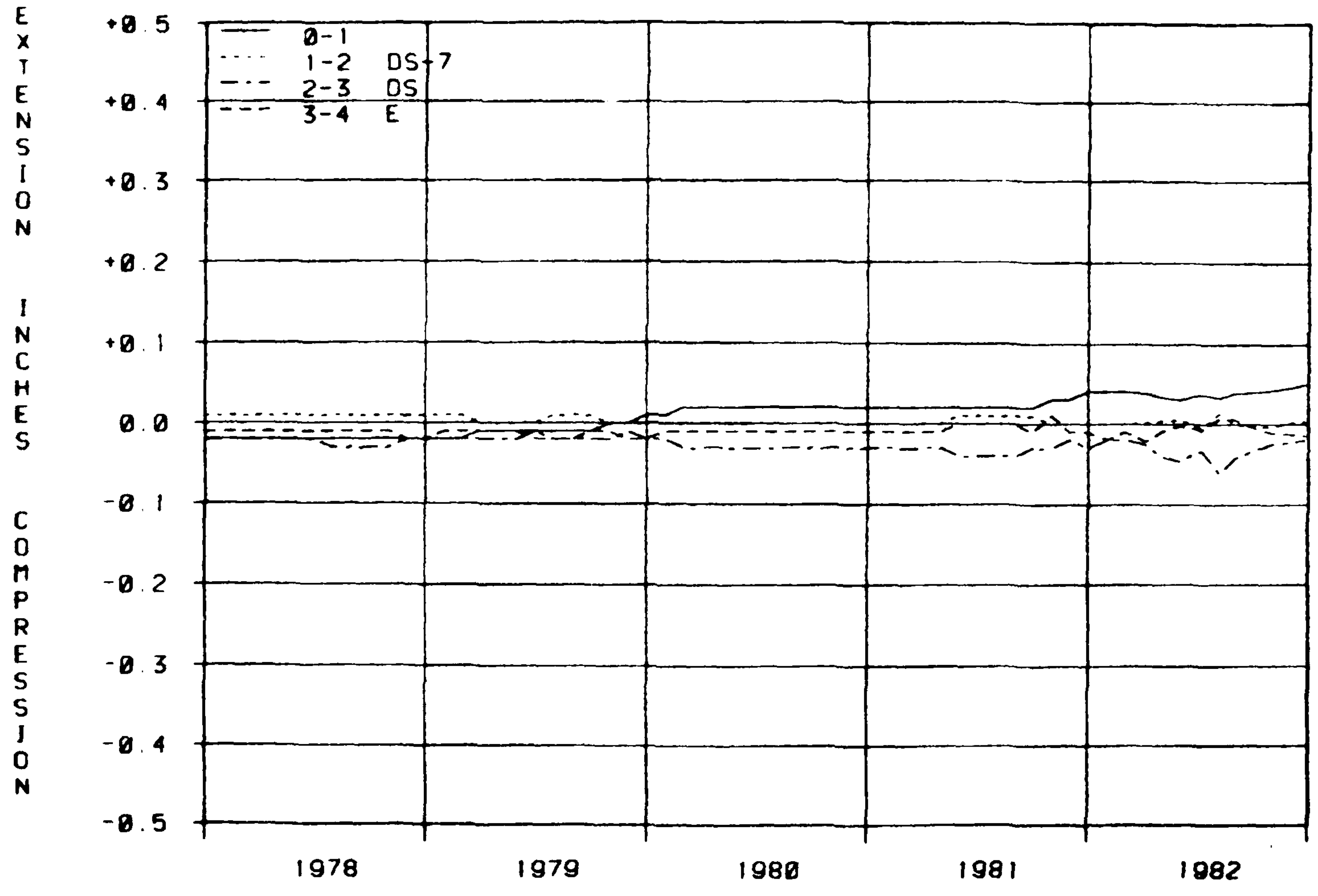


LIBBY LEFT BANK L8 (DISPLACEMENT)

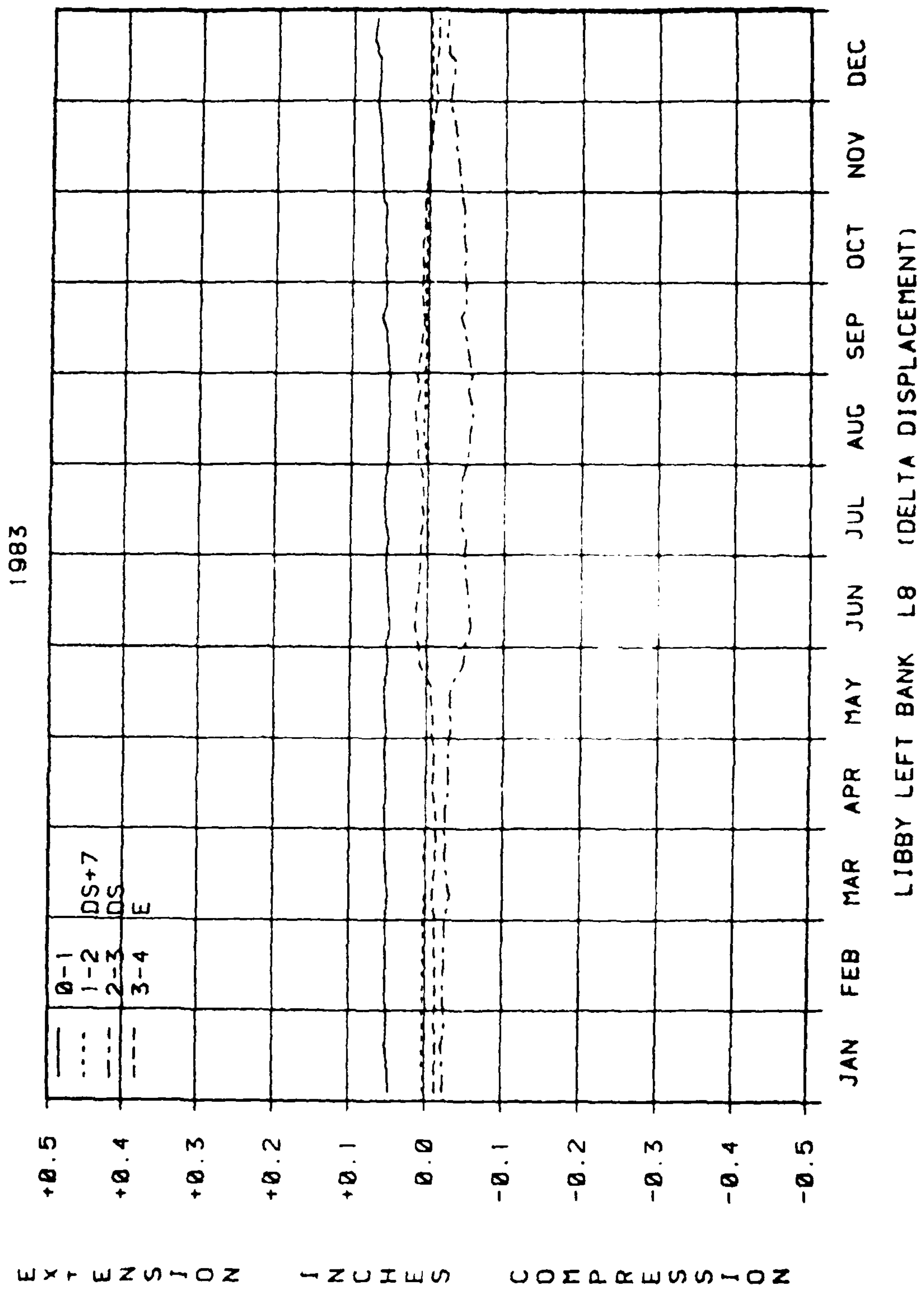

EXTENSION INCHES COMPRESSION
+0.5
+0.4
+0.3
+0.2
+0.1
0.0
-0.1
-0.2
-0.3
-0.4
-0.5
0-1
1-2 DS+7
2-3 DS
3-4 E
1968
1969
1970
1971
1972
LIBBY LEFT BANK L8 (DELTA DISPLACEMENT)

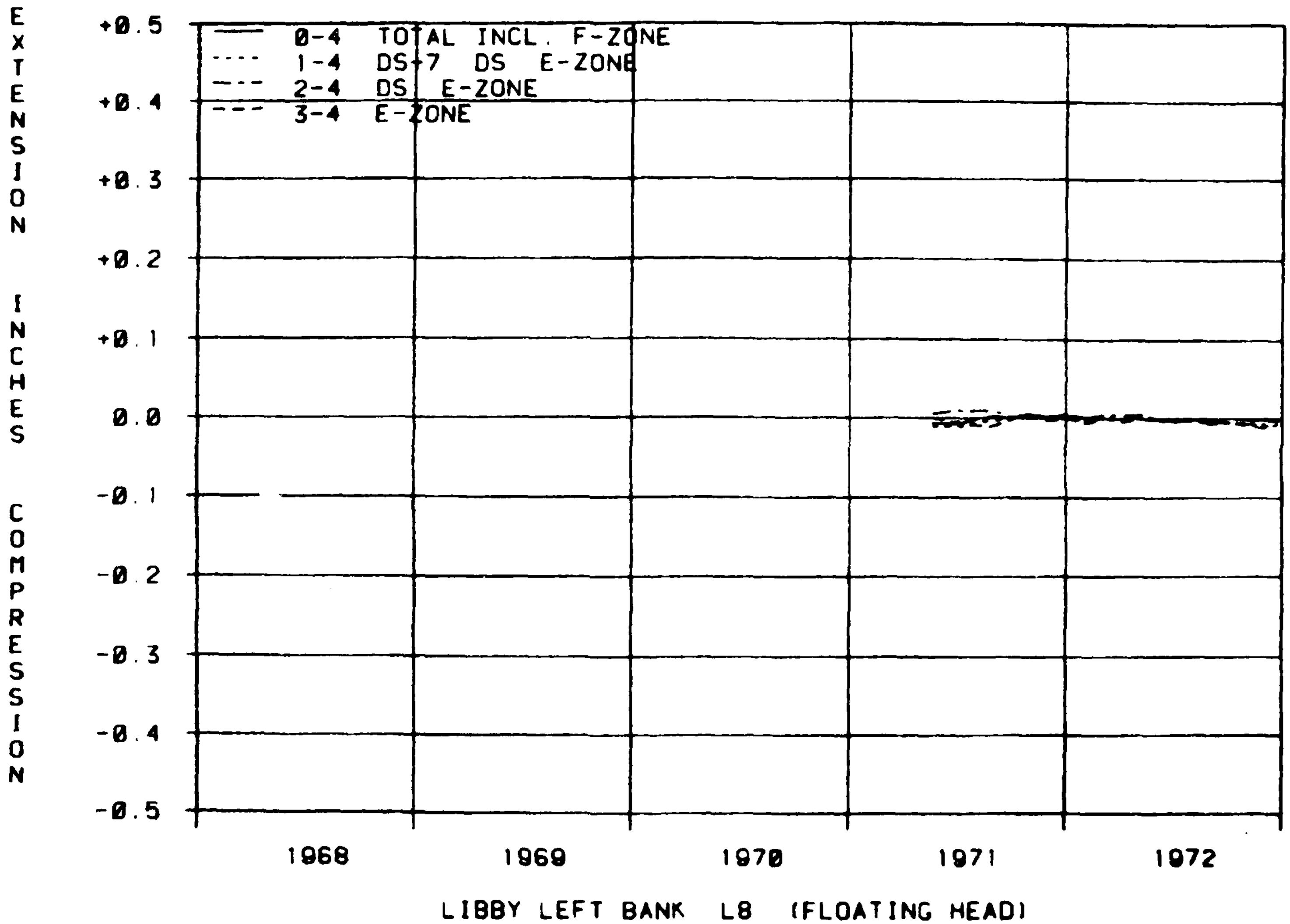


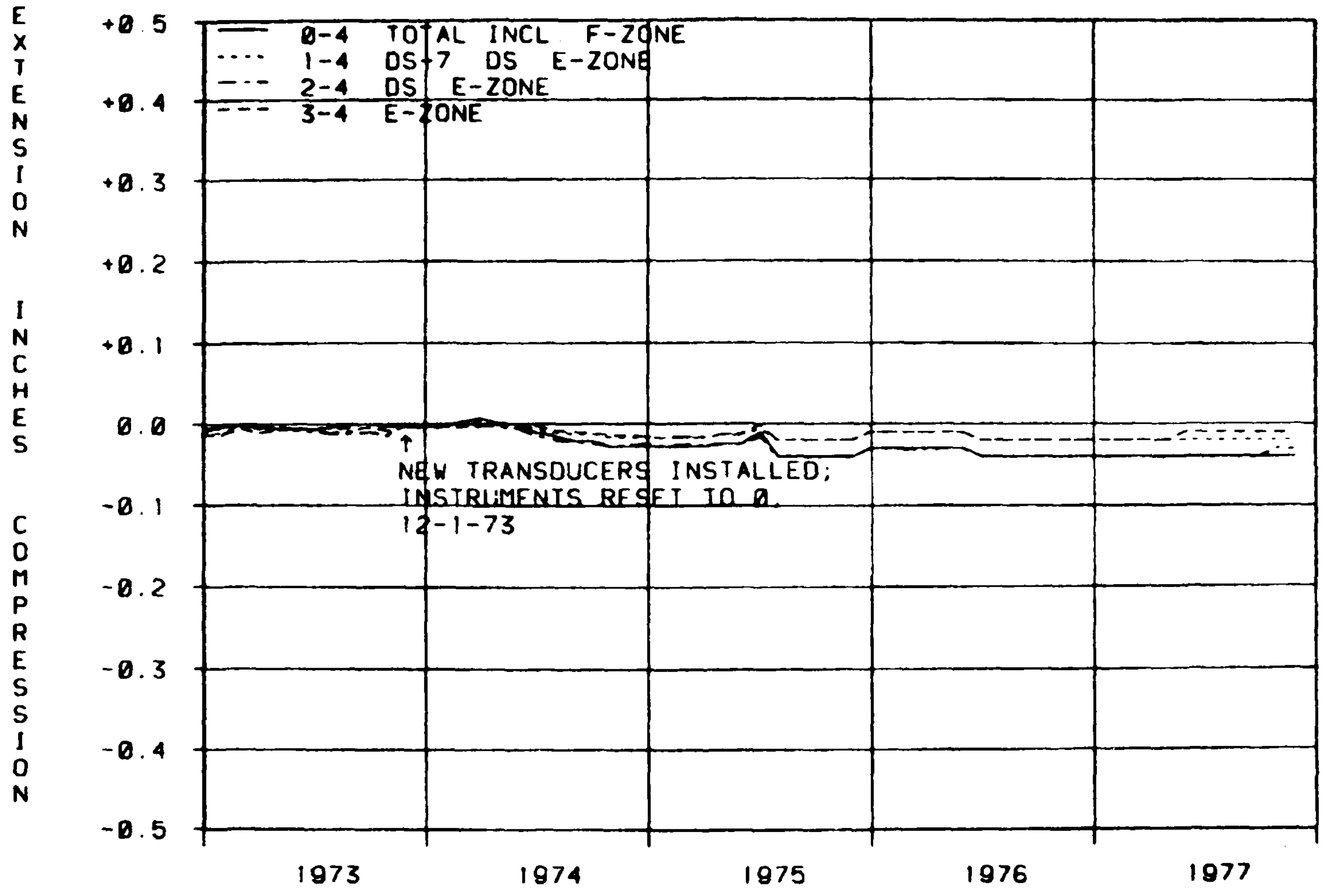
LIBBY LEFT BANK L8 (DELTA DISPLACEMENT)



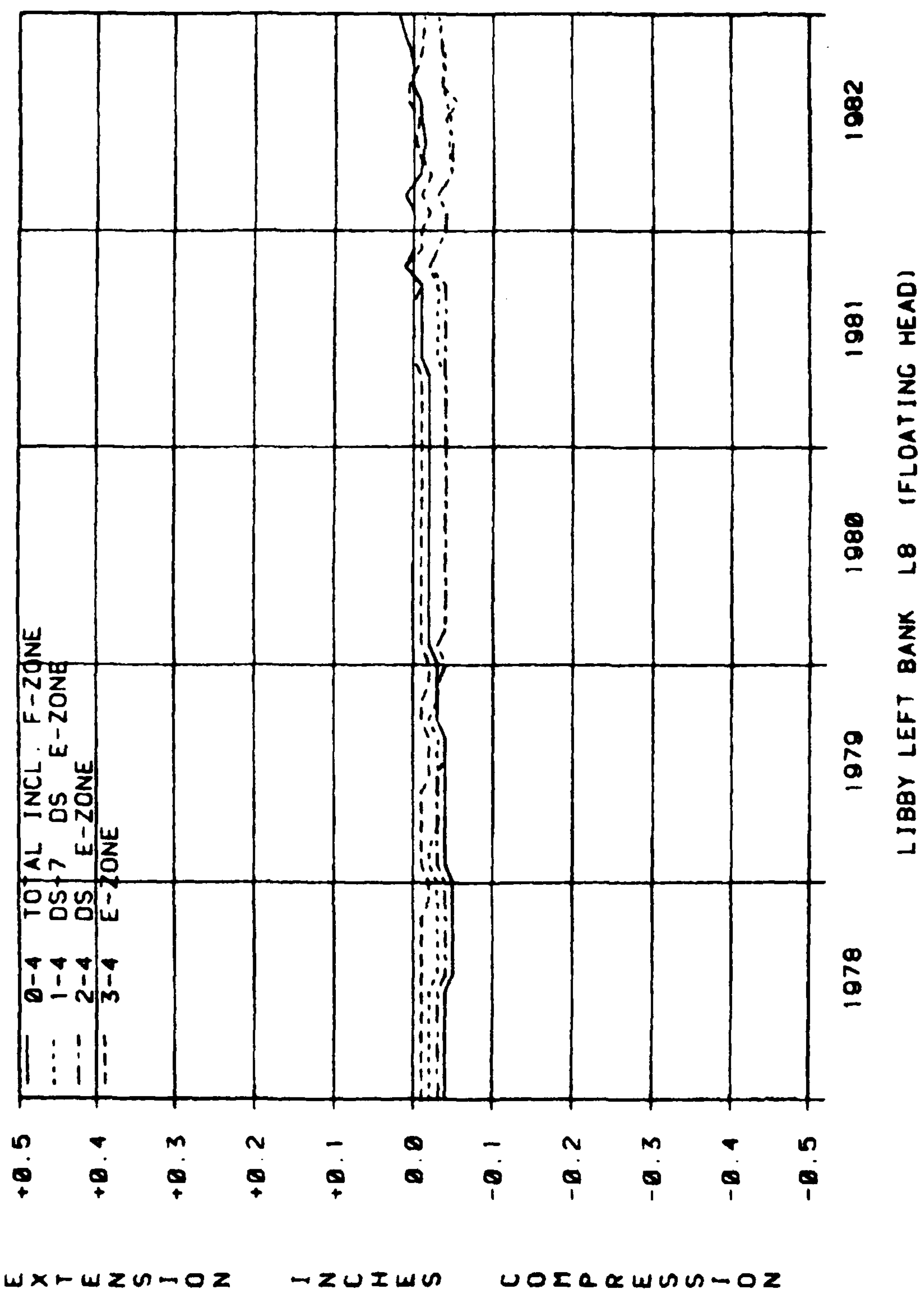
LIBBY LEFT BANK L8 (DELTA DISPLACEMENT)


1983
LIBBY LEFT BANK L8 (DELTA DISPLACEMENT)
0-1 DS+7
1-2 DS
2-3 DS
3-4 E
JAN FEB MAR APR MAY JUN JUL AUG SEP OCT NOV DEC
+0.5 +0.4 +0.3 +0.2 +0.1 0.0 -0.1 -0.2 -0.3 -0.4 -0.5
EXTENSION INCHES COMPRESSION

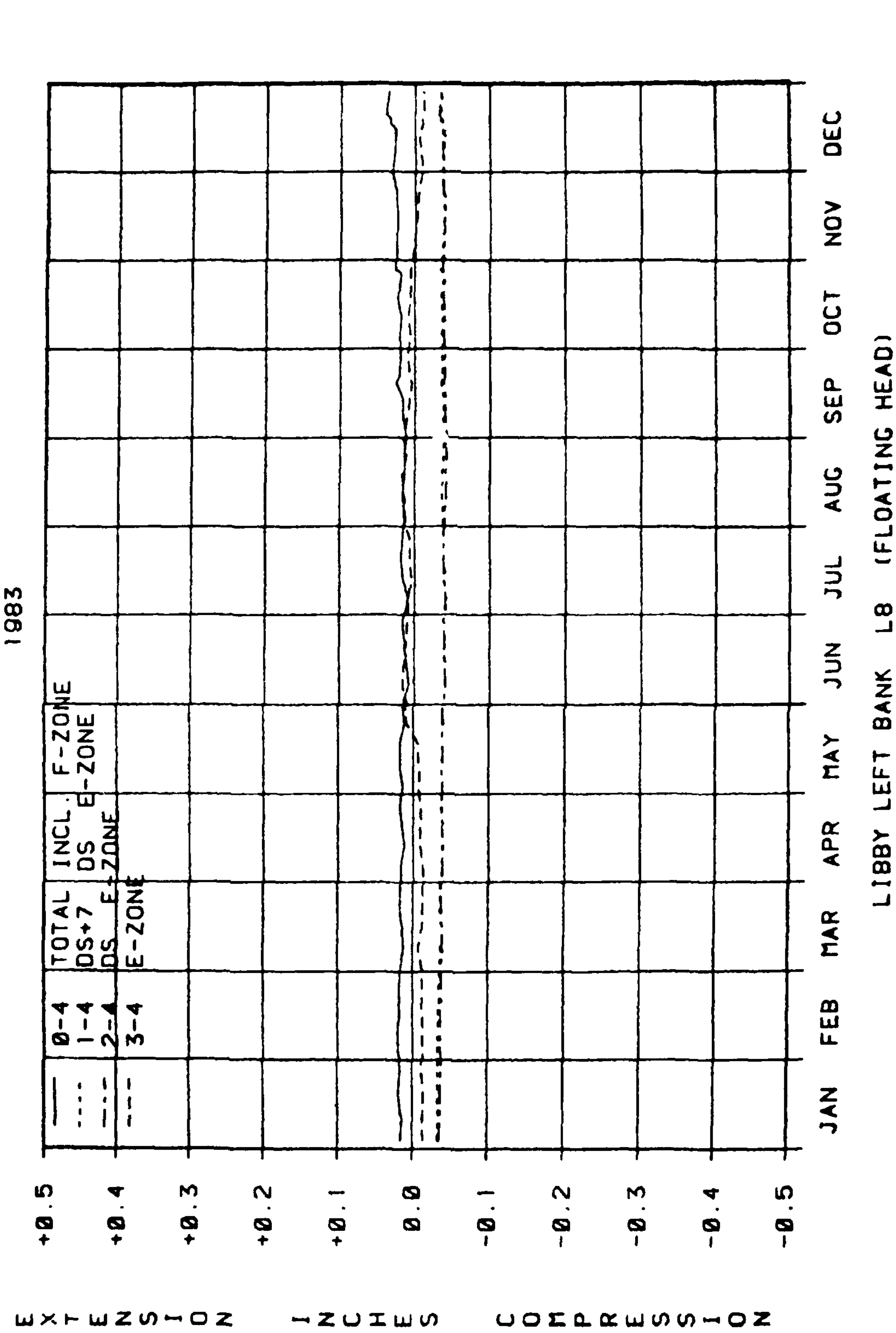

0-4 TOTAL INCL. F-ZONE
1-4 DS+7 DS E-ZONE
2-4 DS E-ZONE
3-4 E-ZONE
EXTENSION INCHES COMPRESSION
+0.5
+0.4
+0.3
+0.2
+0.1
0.0
-0.1
-0.2
-0.3
-0.4
-0.5
1968
1969
1970
1971
1972
LIBBY LEFT BANK L8 (FLOATING HEAD)

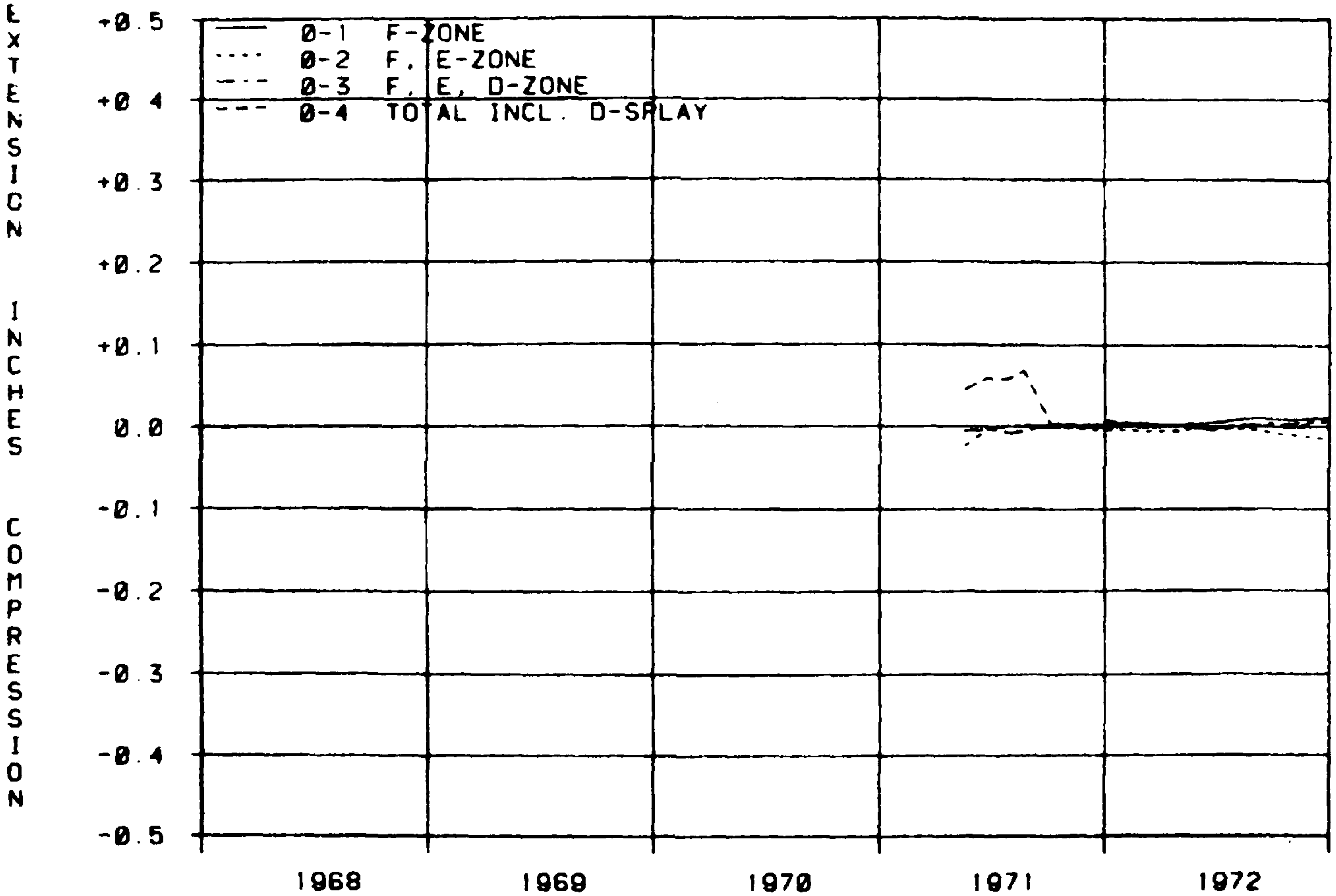


LIBBY LEFT BANK L8 (FLOATING HEAD)

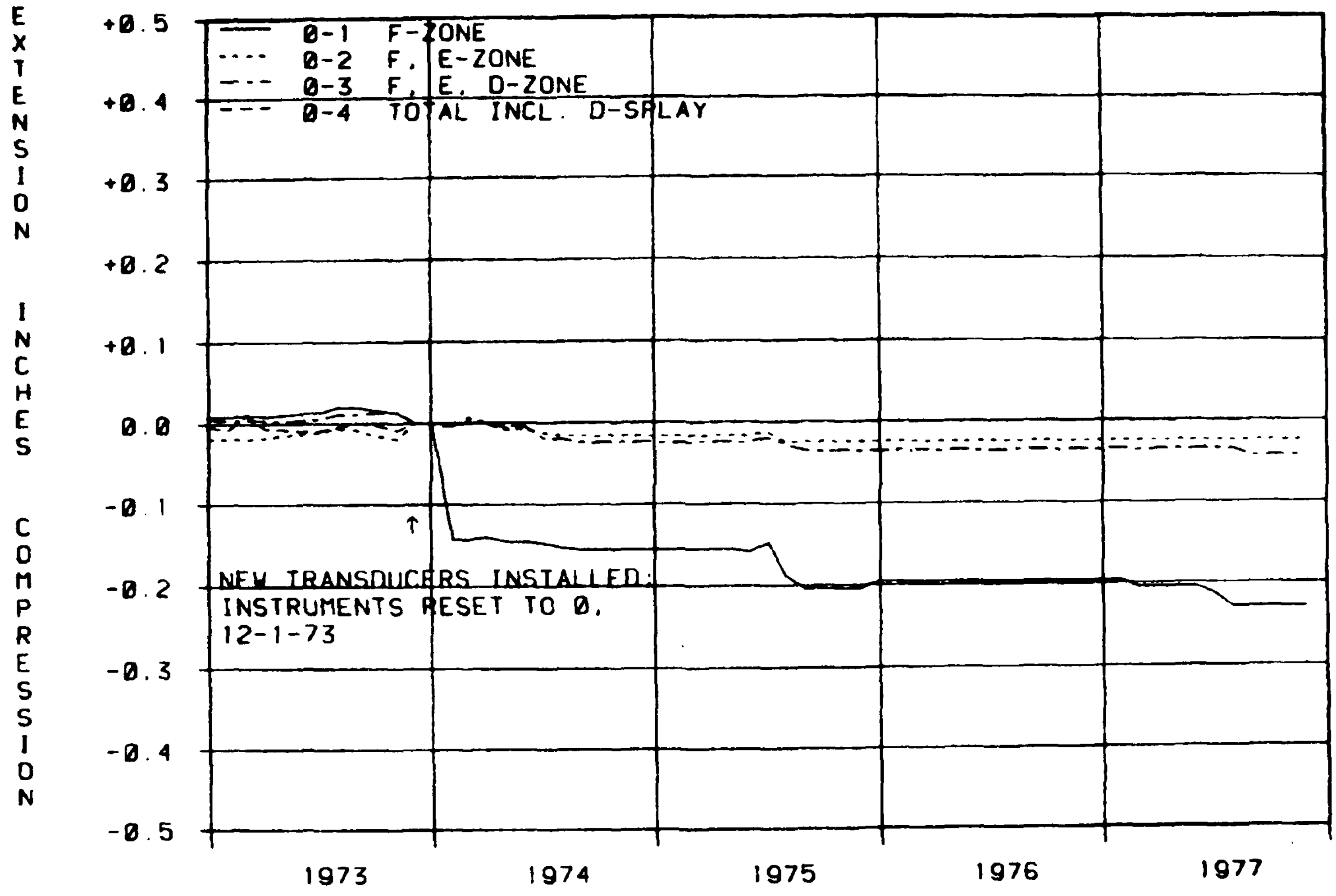


Ø-4 TOTAL INCL. F-ZONE
1-4 DS-7 DS E-ZONE
2-4 DS E-ZONE
3-4 E-ZONE
+Ø.5
+Ø.4
+Ø.3
+Ø.2
+Ø.1
Ø.Ø
-Ø.1
-Ø.2
-Ø.3
-Ø.4
-Ø.5
EXTENSION INCHES COMPRESSION
1978
1979
198Ø
1981
1982
LIBBY LEFT BANK L8 (FLOATING HEAD)

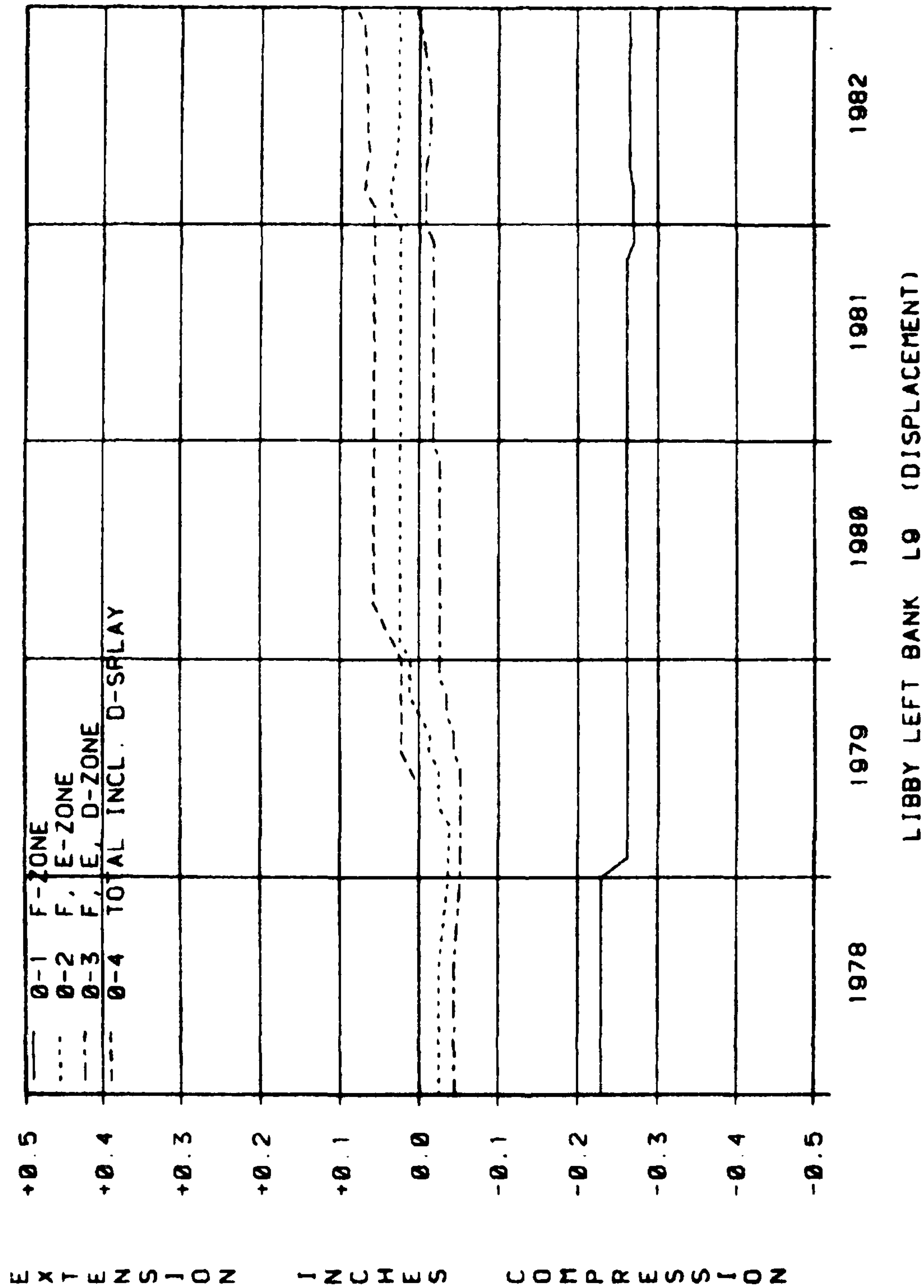

1983
Ø-4 TOTAL INCL. F-ZONE
1-4 DS+7 DS E-ZONE
2-4 DS E-ZONE
3-4 E-ZONE
JAN FEB MAR APR MAY JUN JUL AUG SEP OCT NOV DEC
LIBBY LEFT BANK LB (FLOATING HEAD)
+Ø.5 +Ø.4 +Ø.3 +Ø.2 +Ø.1 Ø.Ø -Ø.1 -Ø.2 -Ø.3 -Ø.4 -Ø.5
EXTENSION INCHES COMPRESSION

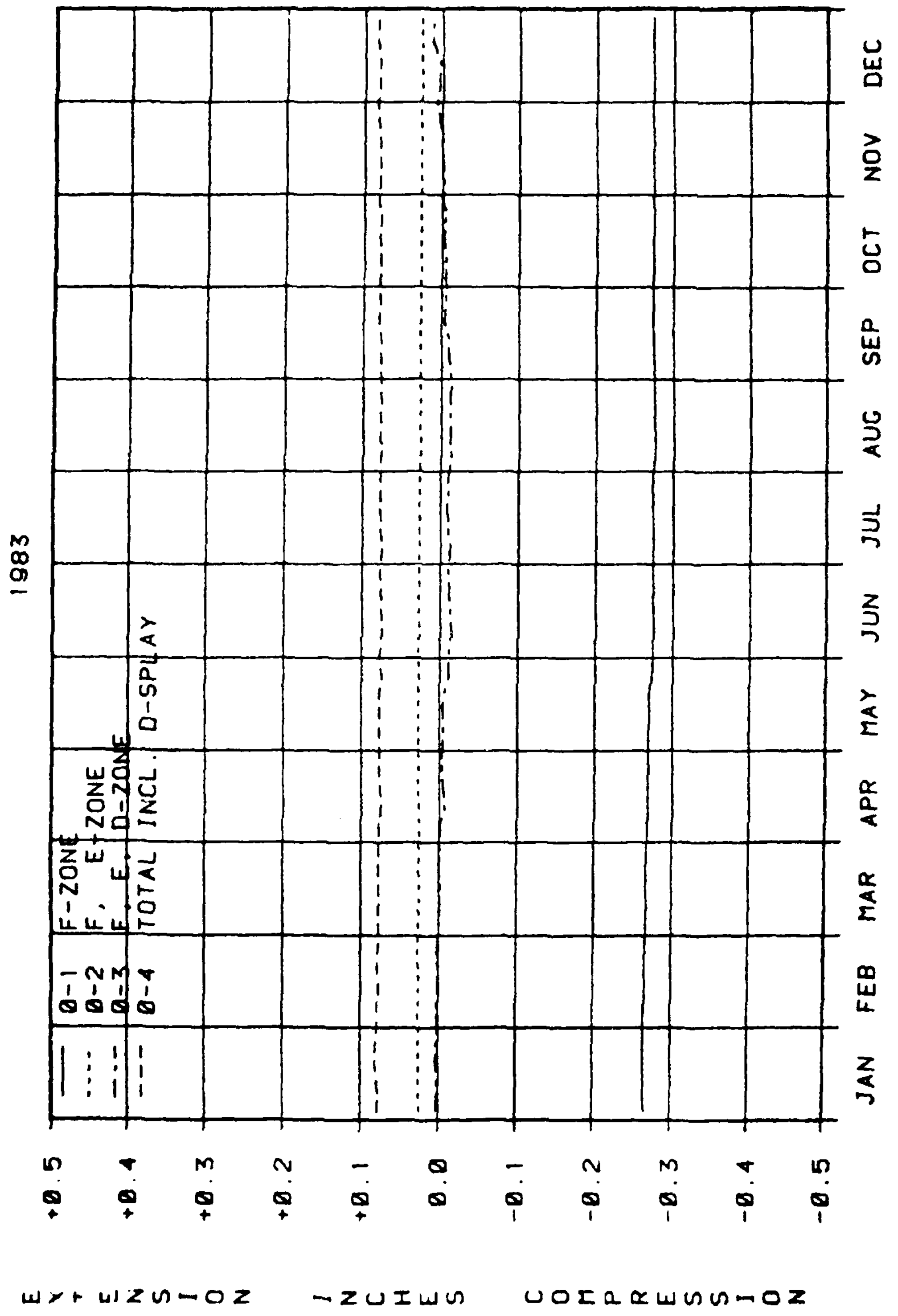


LIBBY LEFT BANK L9 (DISPLACEMENT)

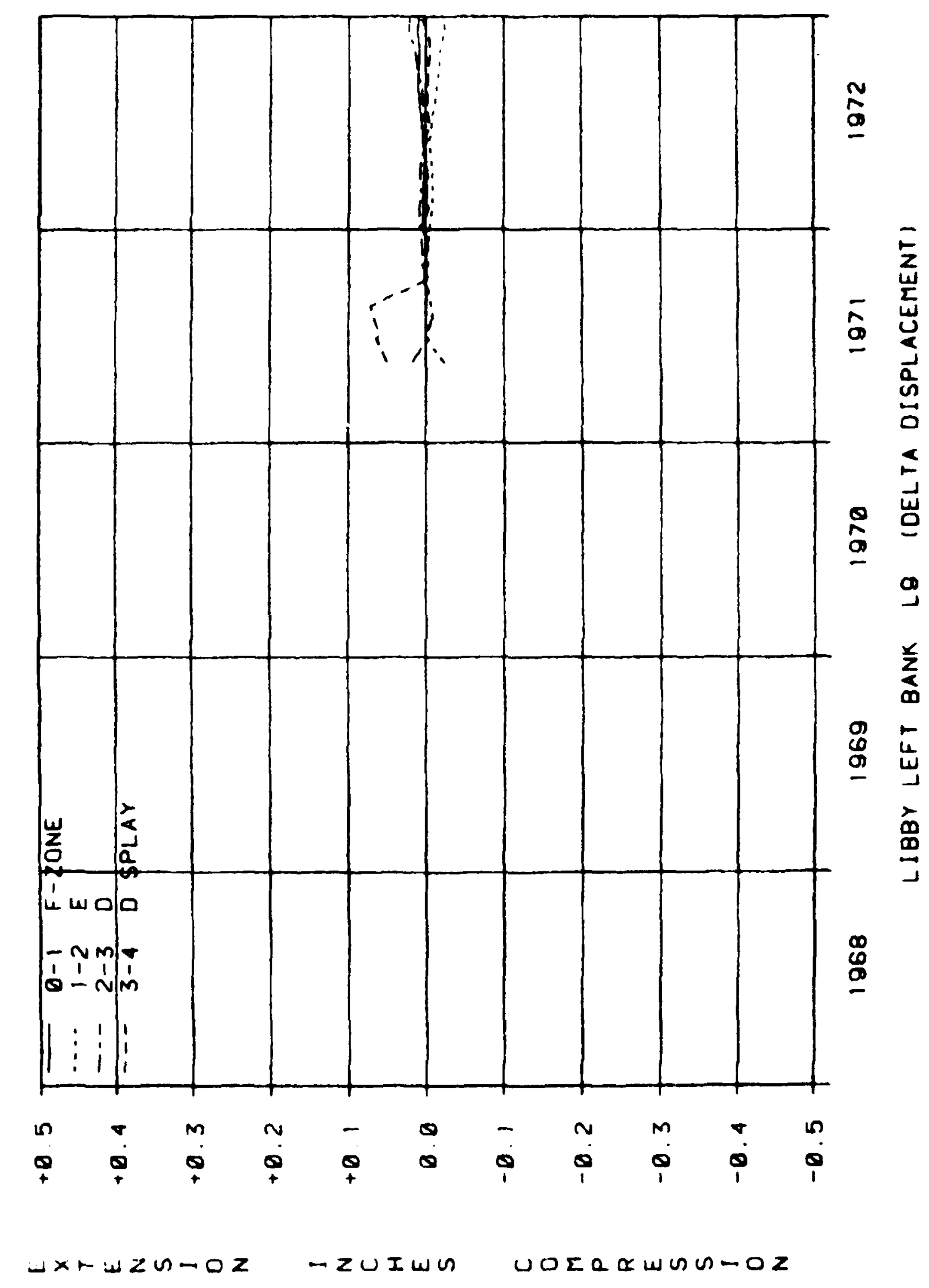


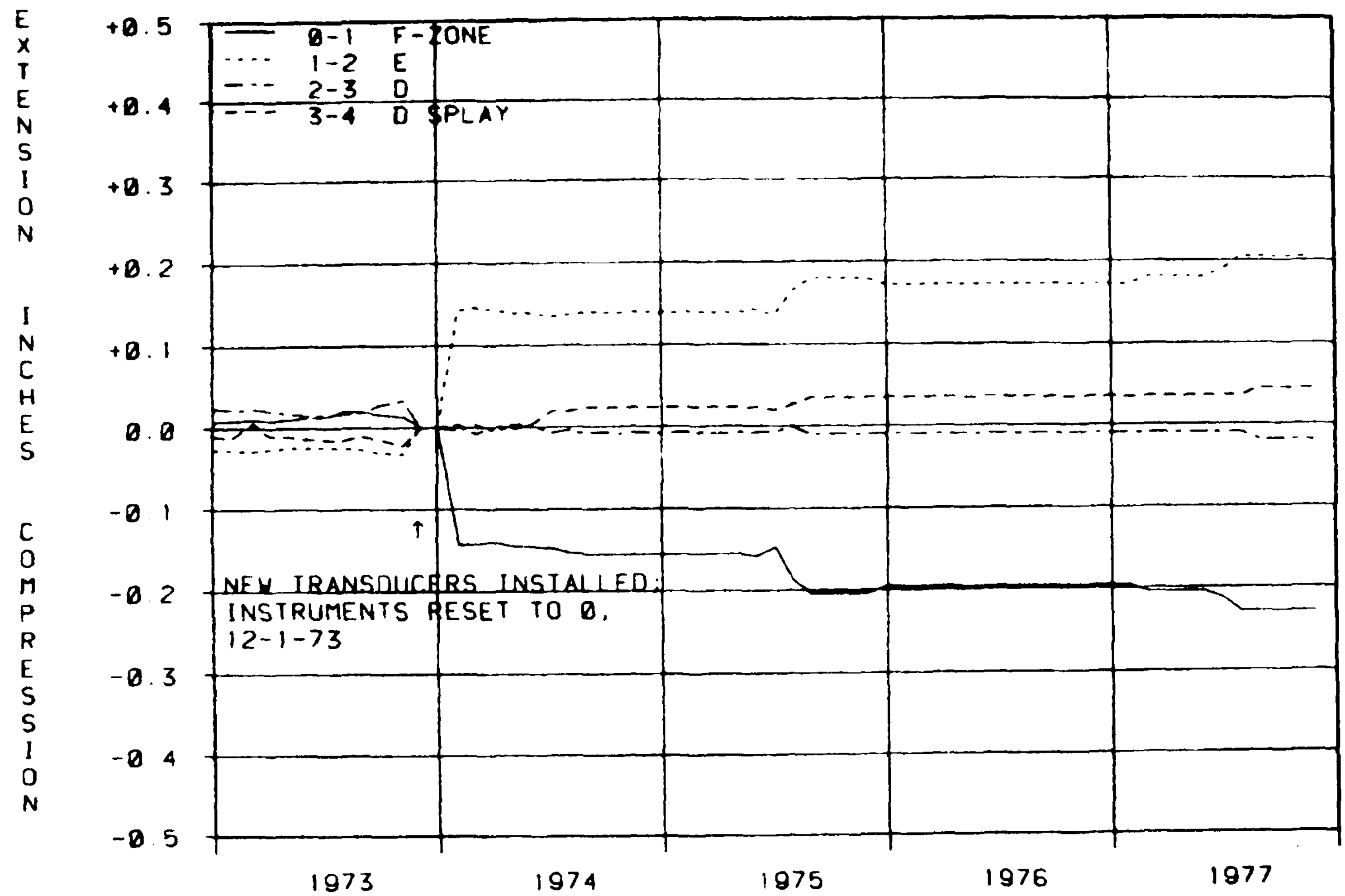
LIBBY LEFT BANK L9 (DISPLACEMENT)


0-1 F-ZONE
0-2 F, E-ZONE
0-3 F, E, D-ZONE
0-4 TOTAL INCL. D-SPLAY
+0.5
+0.4
+0.3
+0.2
+0.1
0.0
-0.1
-0.2
-0.3
-0.4
-0.5
EXTENSION INCHES COMPRESSION
1978
1979
1980
1981
1982
LIBBY LEFT BANK L9 (DISPLACEMENT)

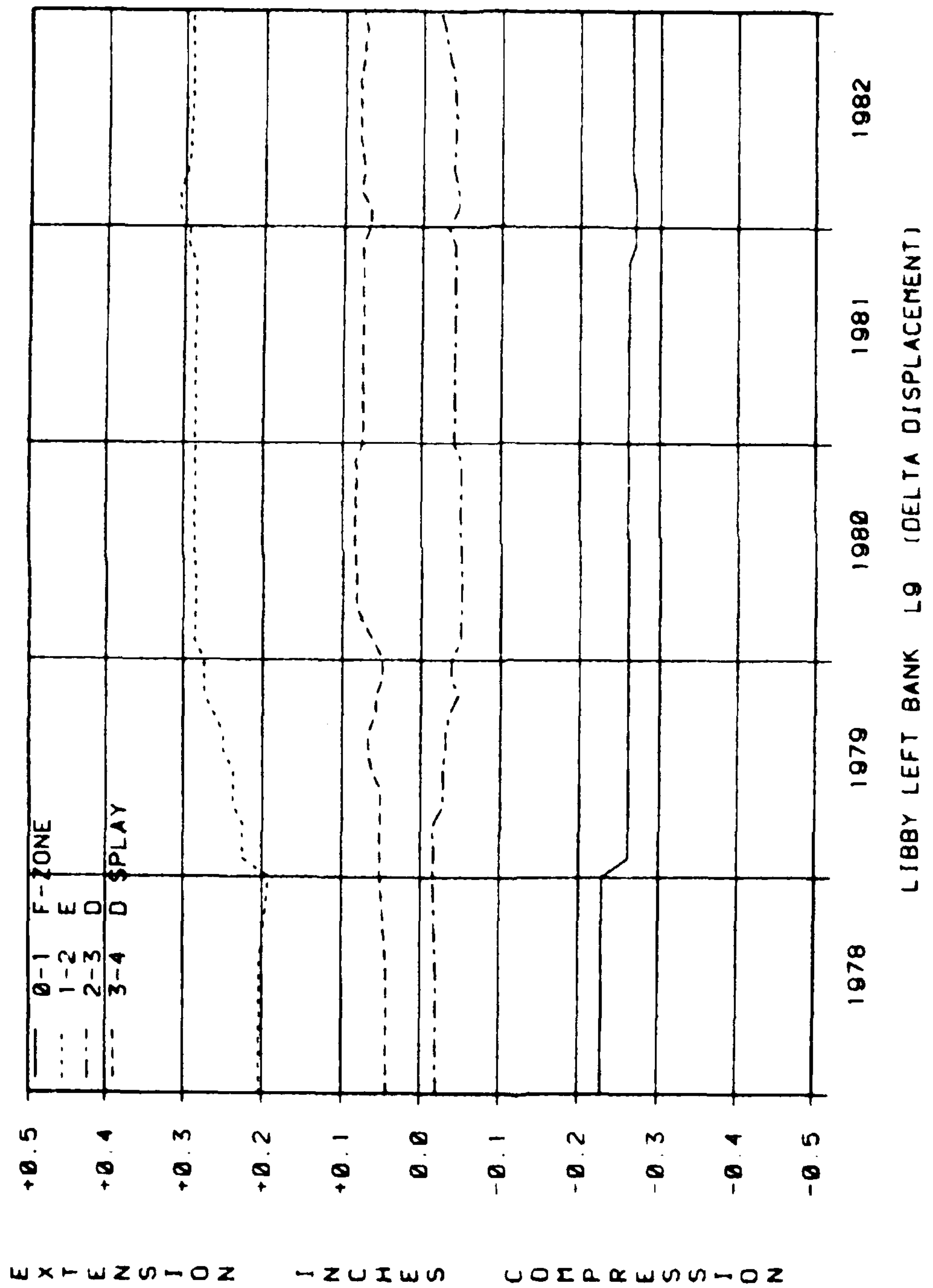


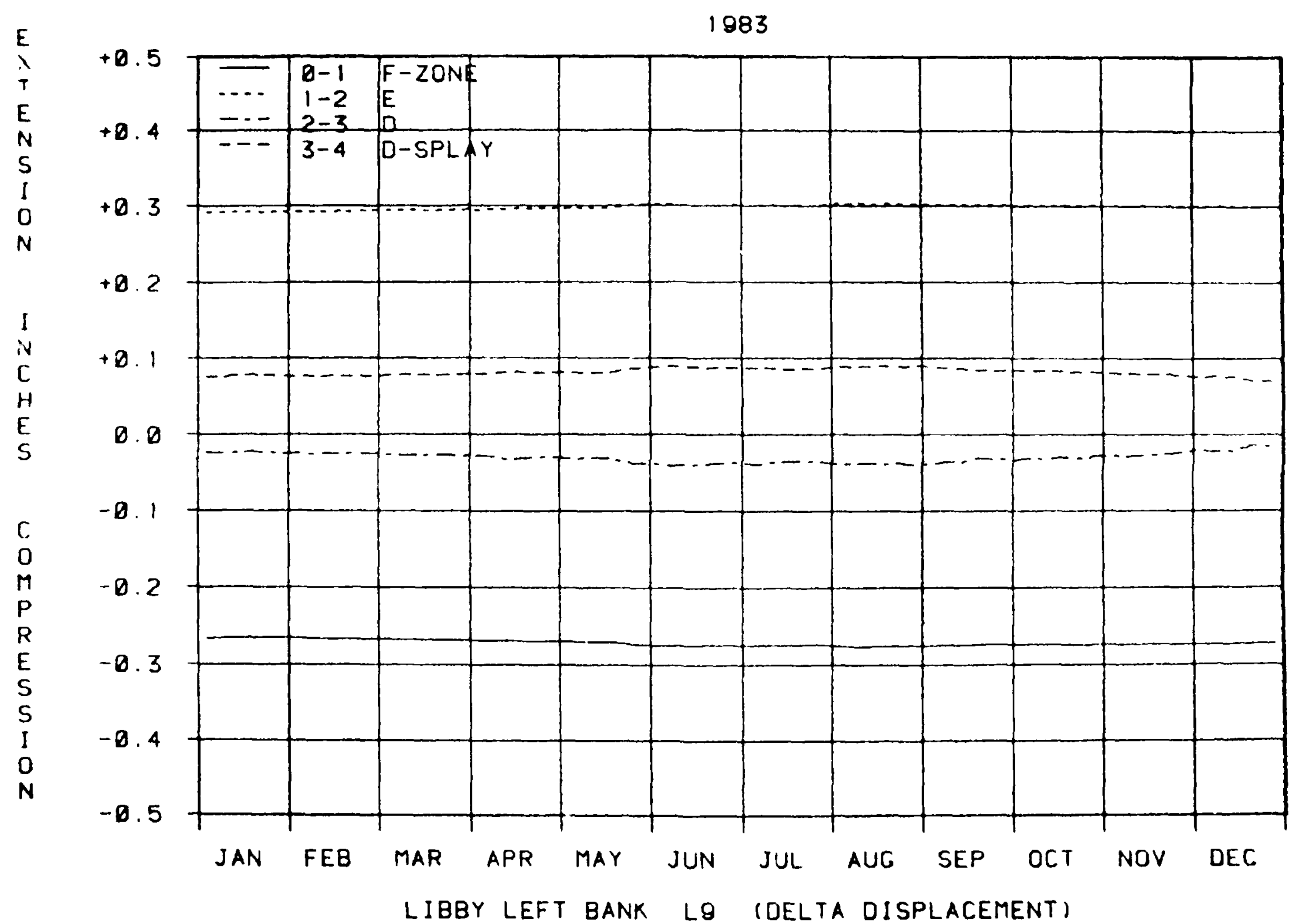
LIBBY LEFT BANK L9 (DISPLACEMENT)


LIBBY LEFT BANK L8 (DELTA DISPLACEMENT)
0-1 F-ZONE
1-2 E
2-3 D
3-4 D SPLAY
1968
1969
1970
1971
1972
+0.5
+0.4
+0.3
+0.2
+0.1
0.0
-0.1
-0.2
-0.3
-0.4
-0.5
EXTENSION INCHES COMPRESSION

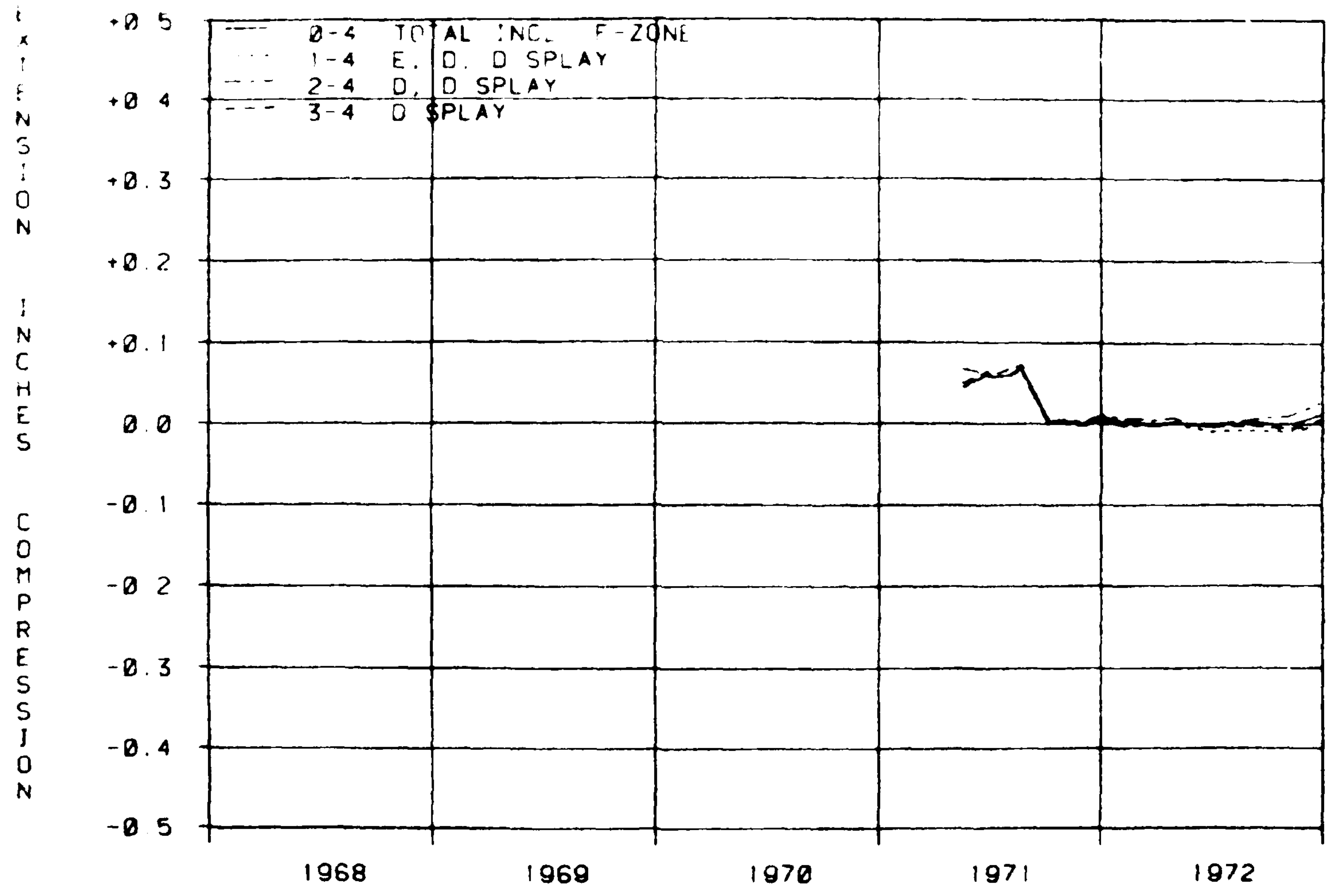


LIBBY LEFT BANK L9 (DELTA DISPLACEMENT)

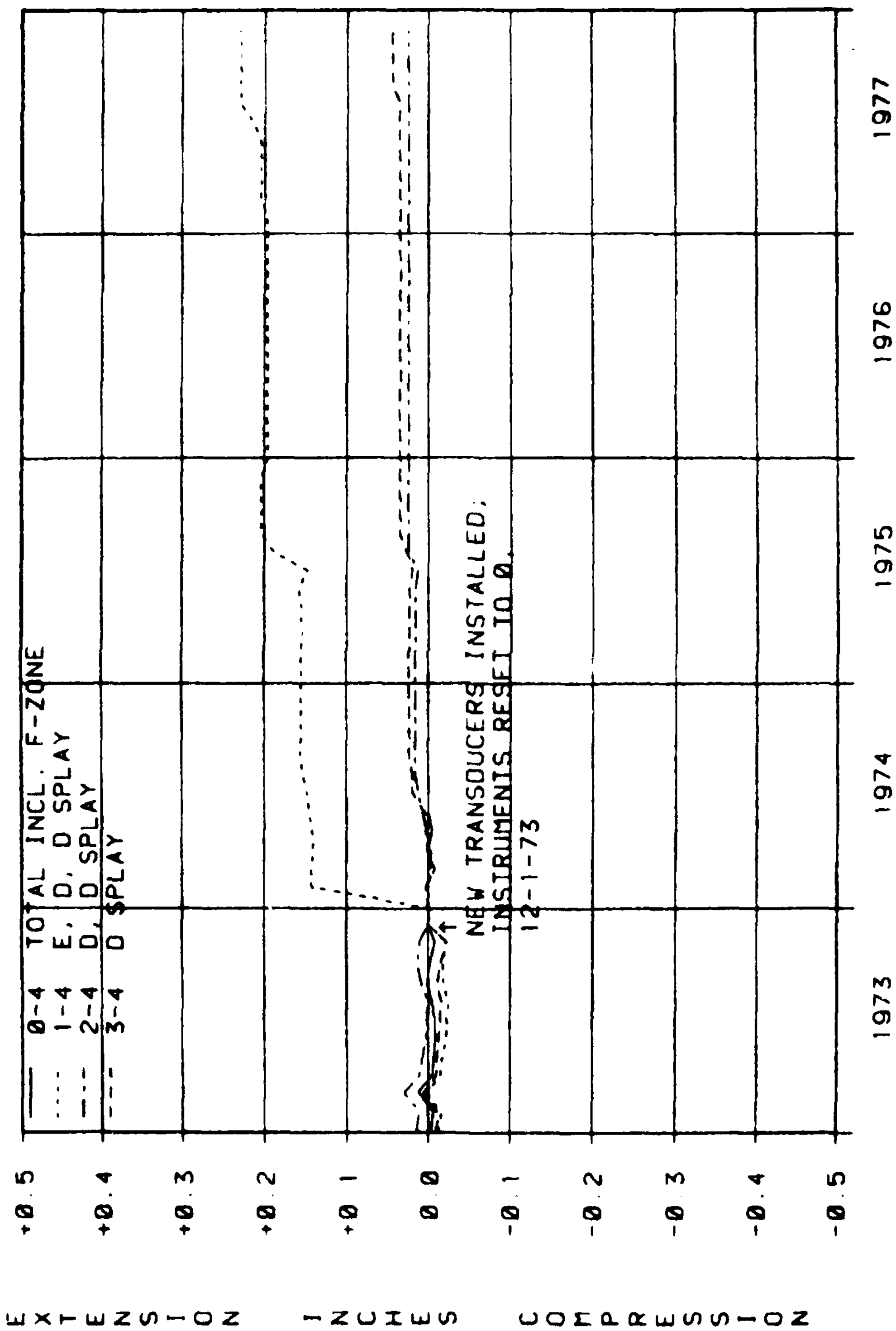

LIBBY LEFT BANK L9 (DELTA DISPLACEMENT)
0-1 F-ZONE
1-2 E
2-3 D
3-4 D SPLAY
1978
1979
1980
1981
1982
+0.5
+0.4
+0.3
+0.2
+0.1
0.0
-0.1
-0.2
-0.3
-0.4
-0.5
EXTENSION INCHES COMPRESSION



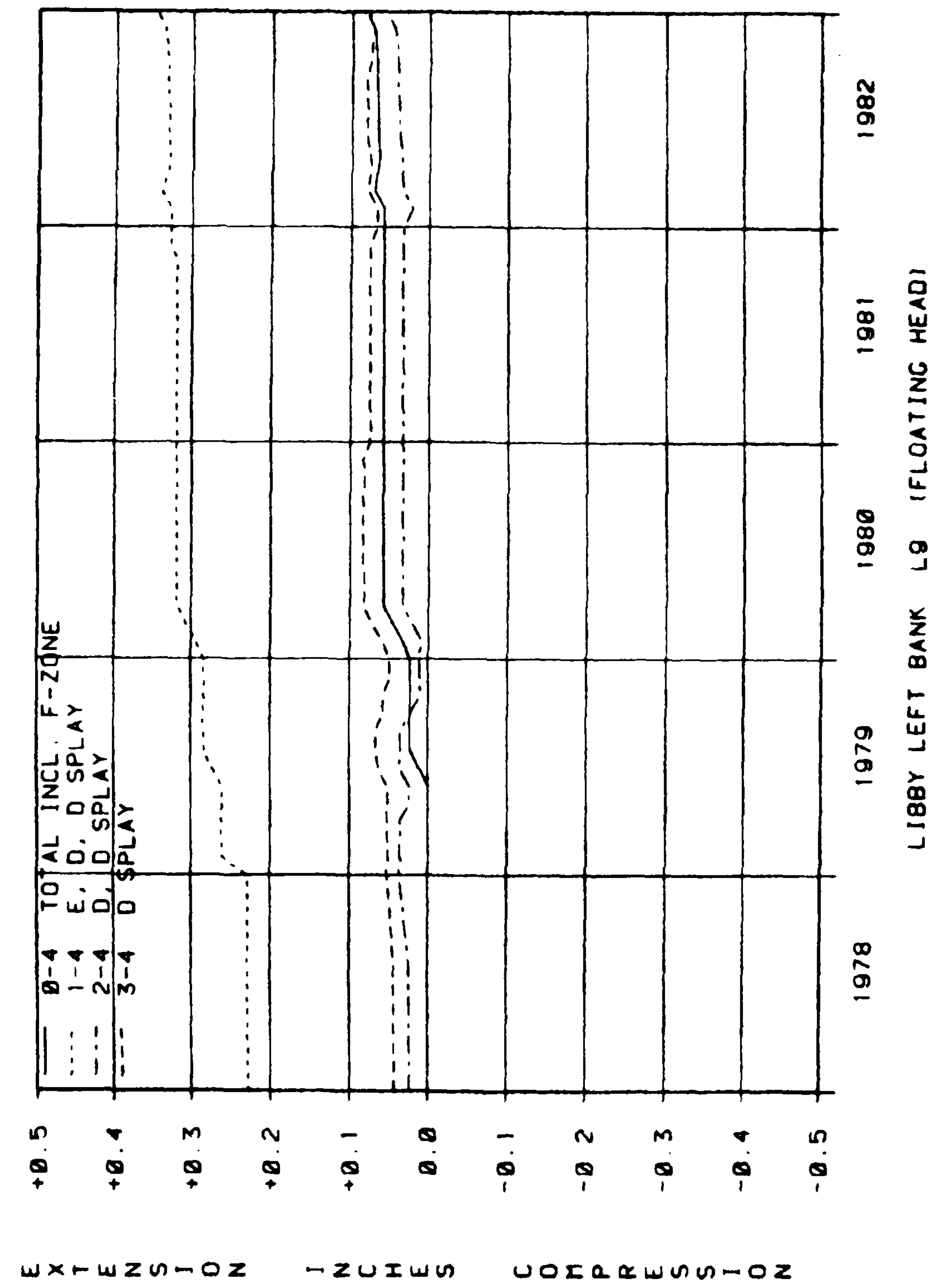
1983
0-1 F-ZONE
1-2 E
2-3 D
3-4 D-SPLAY
EXTENSION INCHES COMPRESSION
+0.5
+0.4
+0.3
+0.2
+0.1
0.0
-0.1
-0.2
-0.3
-0.4
-0.5
JAN FEB MAR APR MAY JUN JUL AUG SEP OCT NOV DEC
LIBBY LEFT BANK L9 (DELTA DISPLACEMENT)

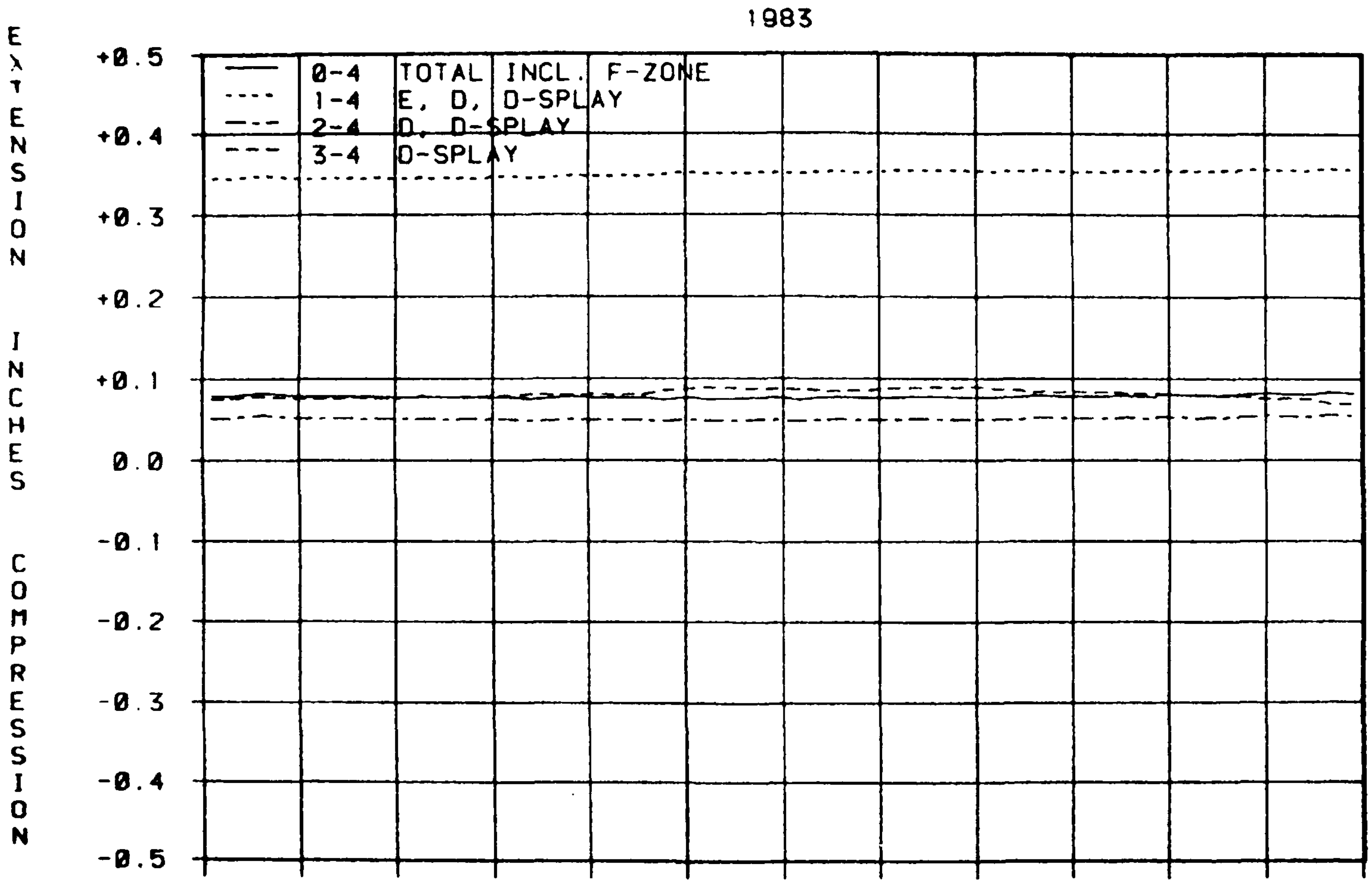


LIBBY LEFT BANK L9 (FLOATING HEAD)

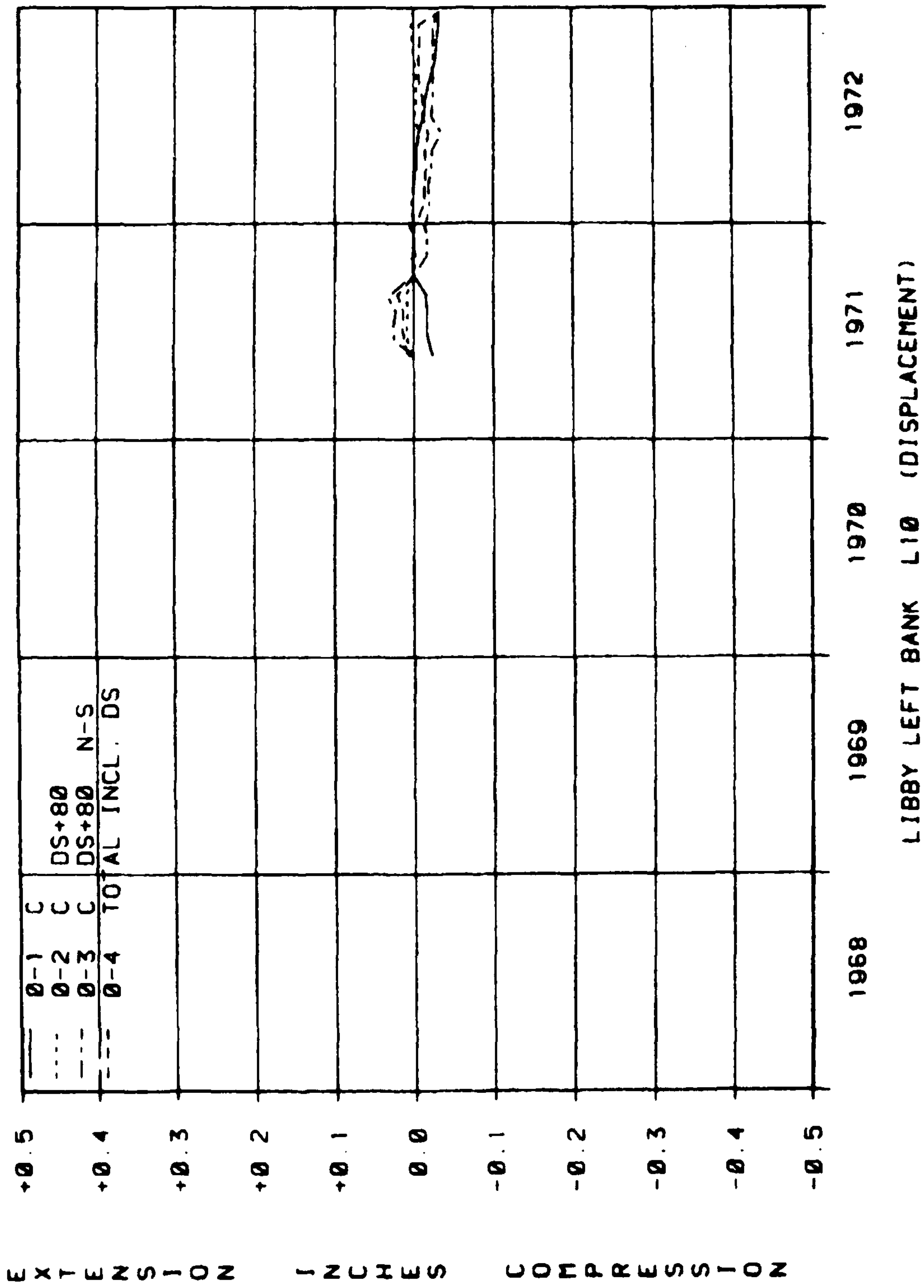


LIBBY LEFT BANK L9 (FLOATING HEAD)

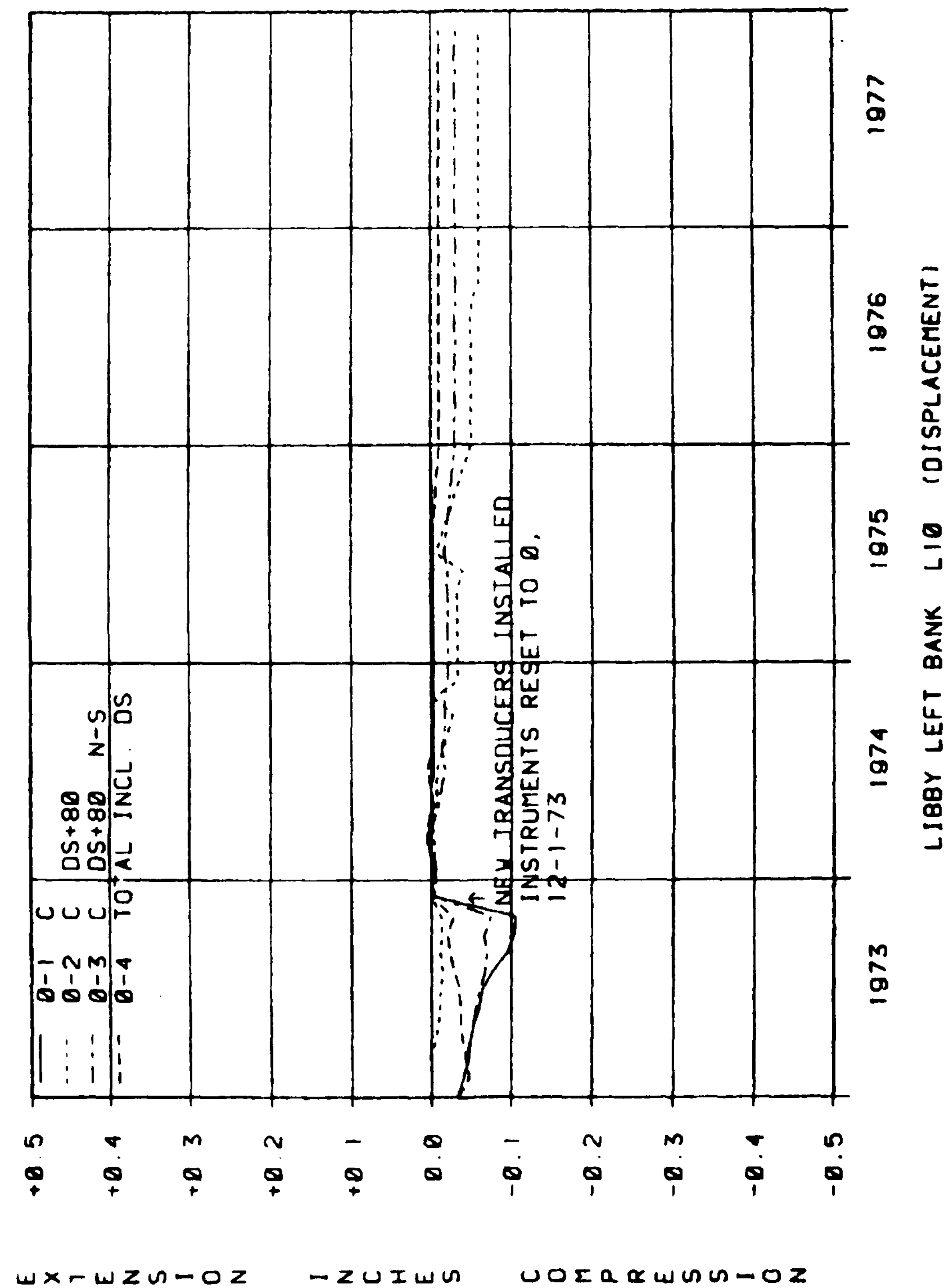

Ø-4 TOTAL INCL. F-ZONE
1-4 E, D, D SPLAY
2-4 D, D SPLAY
3-4 D SPLAY
1978
1979
1980
1981
1982
LIBBY LEFT BANK L9 (FLOATING HEAD)
+Ø.5
+Ø.4
+Ø.3
+Ø.2
+Ø.1
Ø.Ø
-Ø.1
-Ø.2
-Ø.3
-Ø.4
-Ø.5
EXTENSION INCHES COMPRESSION



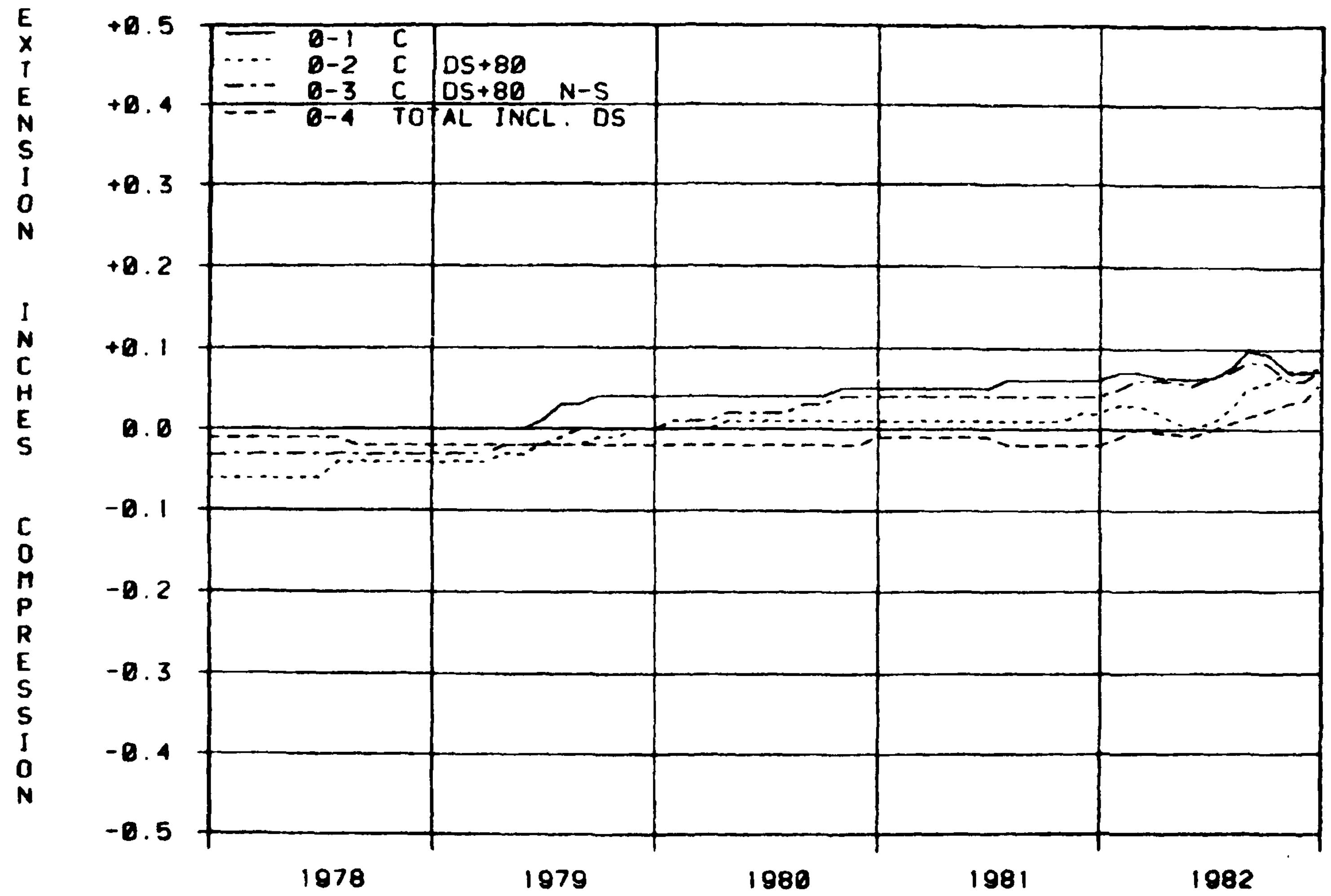
LIBBY LEFT BANK L9 (FLOATING HEAD)



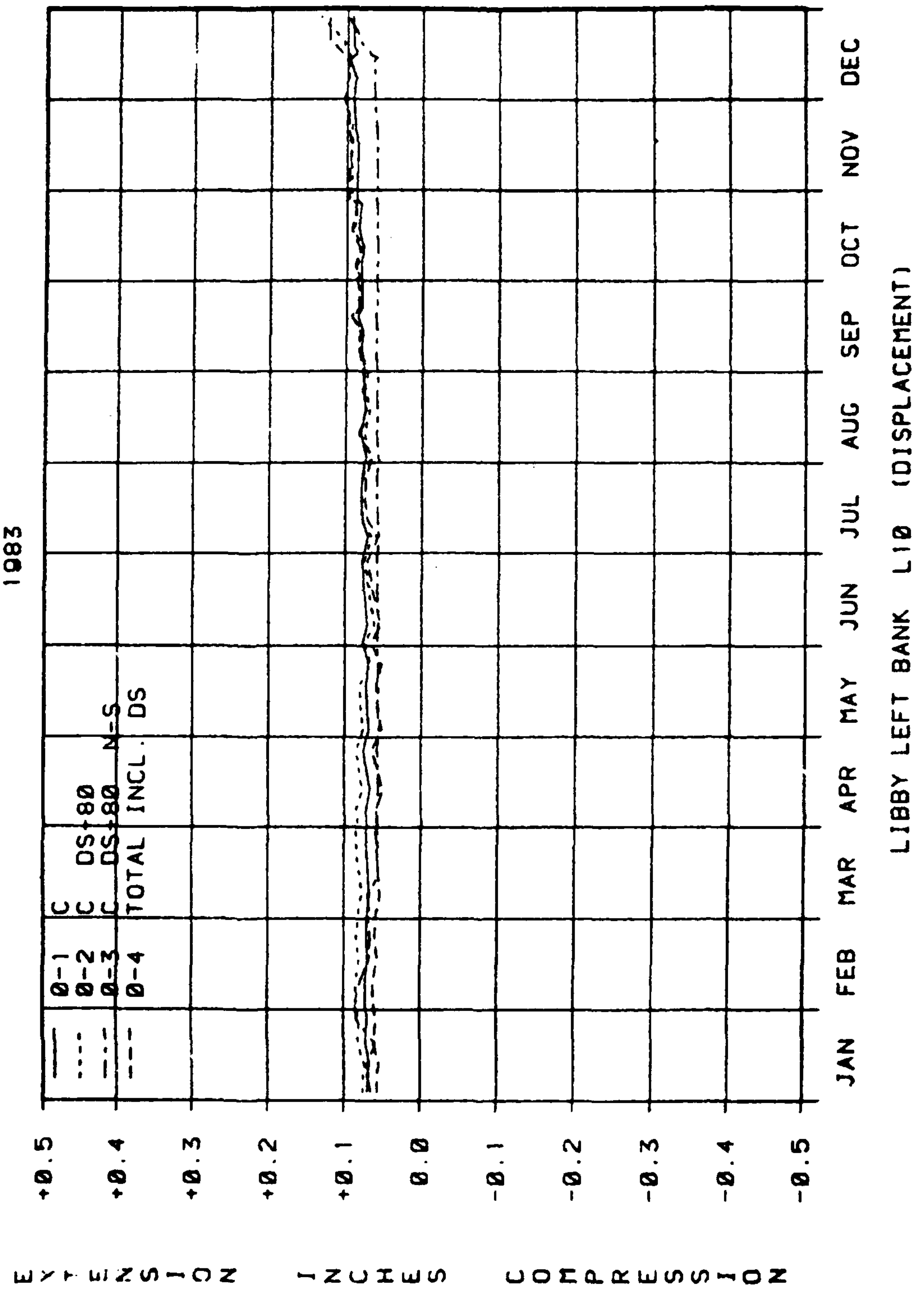
+0.5
+0.4
+0.3
+0.2
+0.1
0.0
-0.1
-0.2
-0.3
-0.4
-0.5
EXTENSION INCHES COMPRESSION
1968
1969
1970
1971
1972
0-1 C DS+80
0-2 C DS+80 N-S
0-3 C TOTAL INCL. DS
0-4
LIBBY LEFT BANK L10 (DISPLACEMENT)

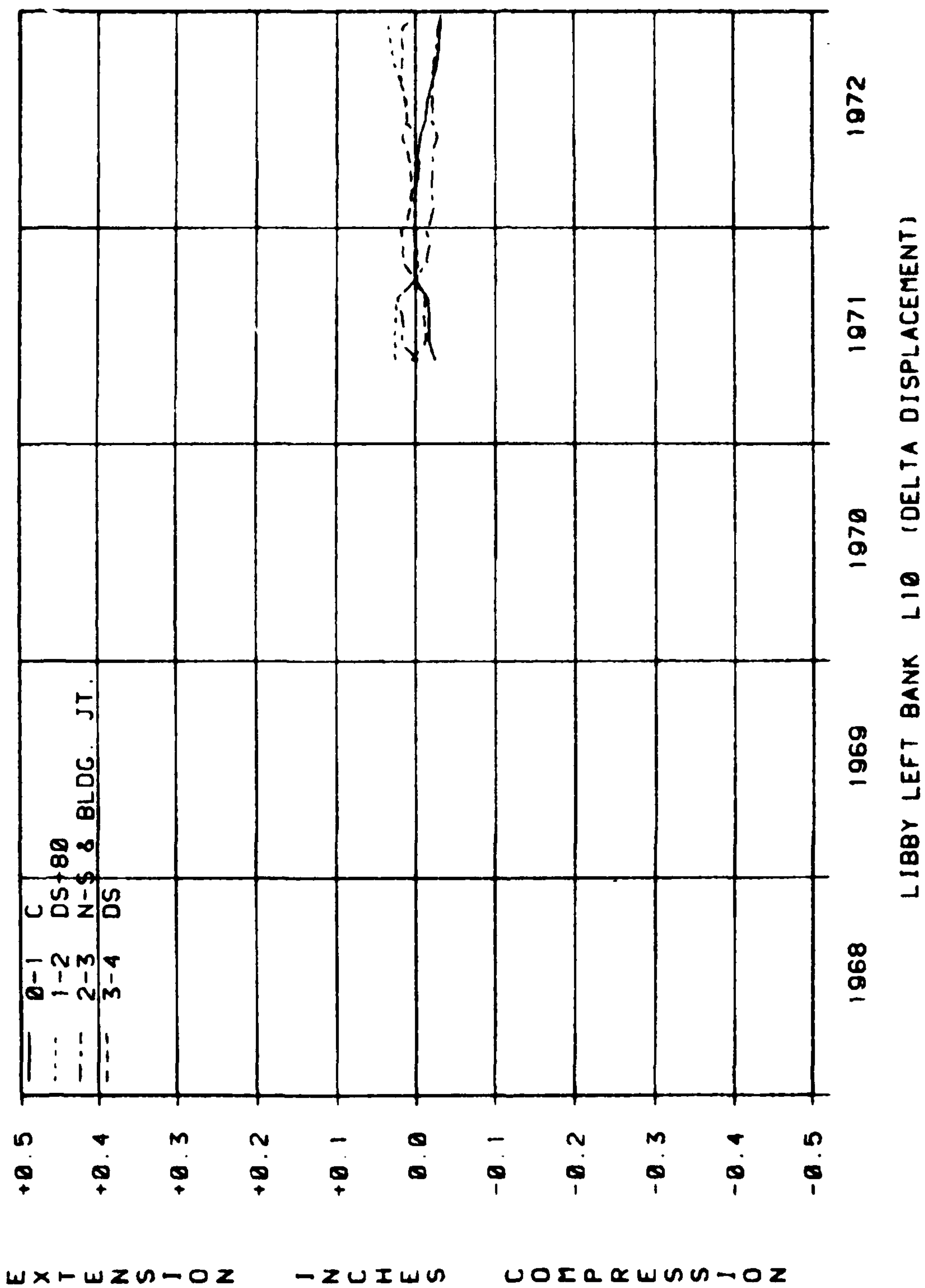


0-1 C
0-2 C DS+80
0-3 C DS+80 N-S
0-4 TOTAL INCL. DS
NEW TRANSDUCERS INSTALLED
INSTRUMENTS RESET TO 0,
12-1-73
1973
1974
1975
1976
1977
+0.5
+0.4
+0.3
+0.2
+0.1
0.0
-0.1
-0.2
-0.3
-0.4
-0.5
EXTENSION
INCHES
COMPRESSION
LIBBY LEFT BANK L10 (DISPLACEMENT)

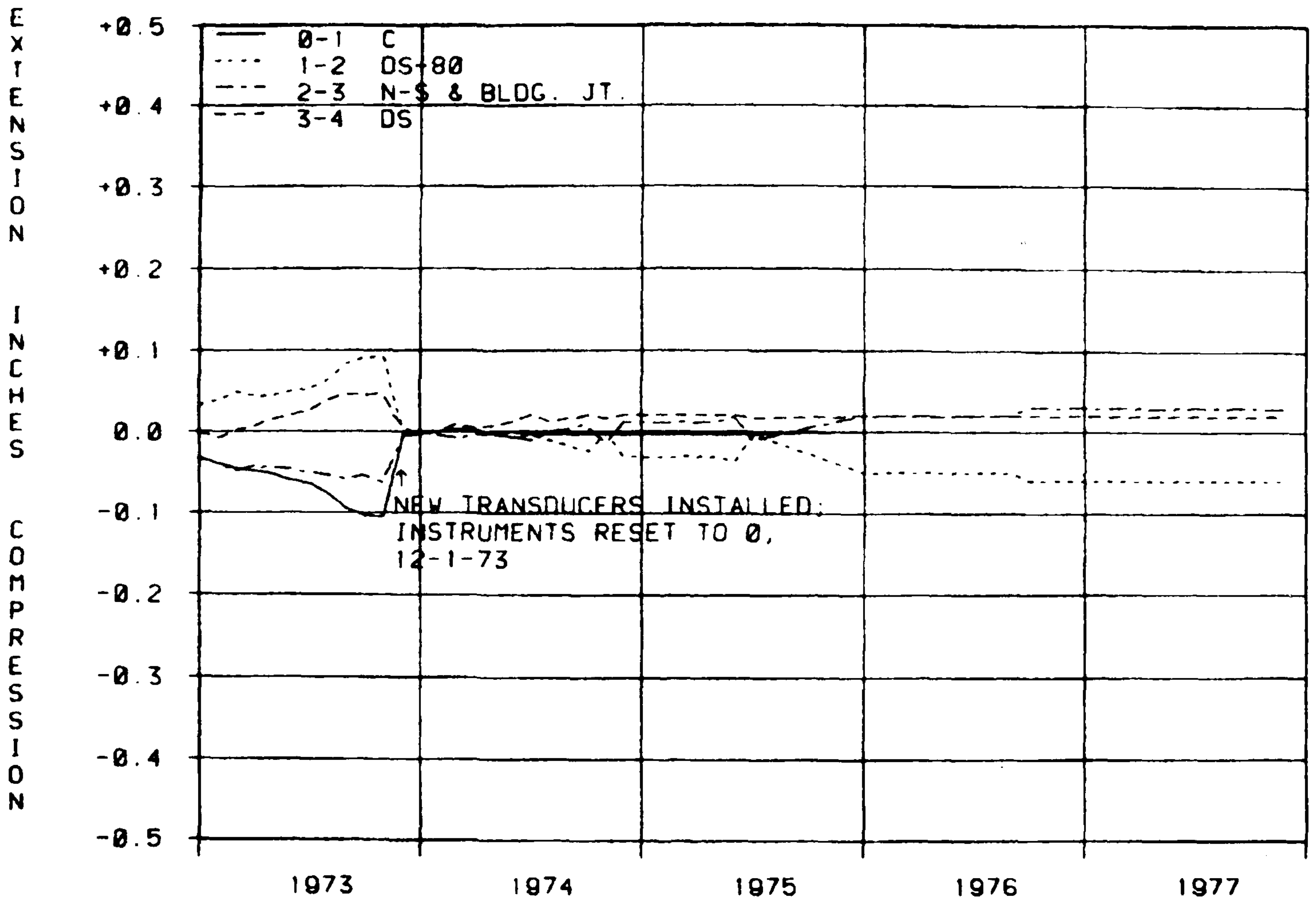


LIBBY LEFT BANK L10 (DISPLACEMENT)

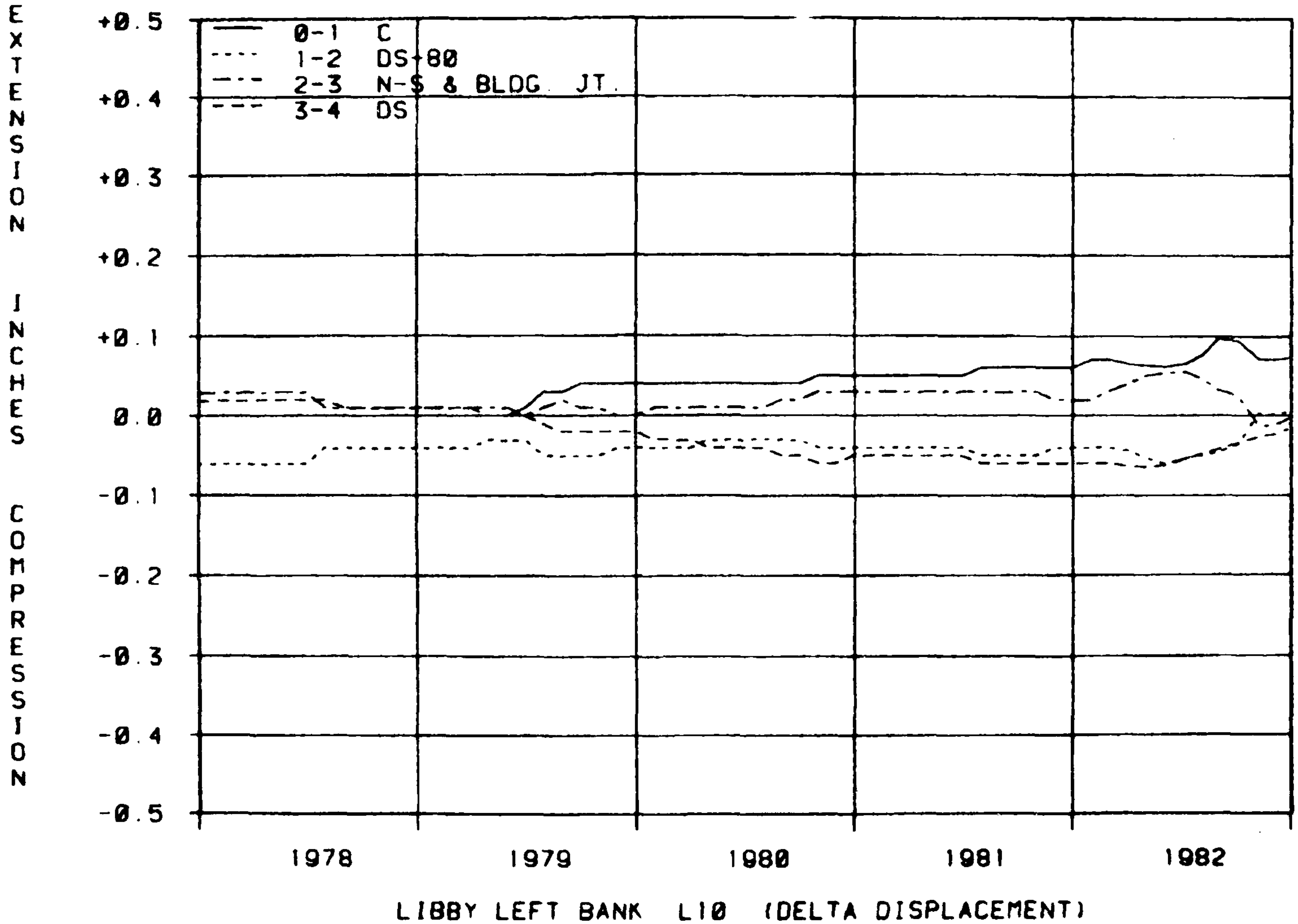

1983
Ø-1 C
Ø-2 C DS+8Ø
Ø-3 C DS+8Ø N-S
Ø-4 TOTAL INCL. DS
JAN FEB MAR APR MAY JUN JUL AUG SEP OCT NOV DEC
LIBBY LEFT BANK L1Ø (DISPLACEMENT)
+Ø.5 +Ø.4 +Ø.3 +Ø.2 +Ø.1 Ø.Ø -Ø.1 -Ø.2 -Ø.3 -Ø.4 -Ø.5
EXTENSION INCHES COMPRESSION



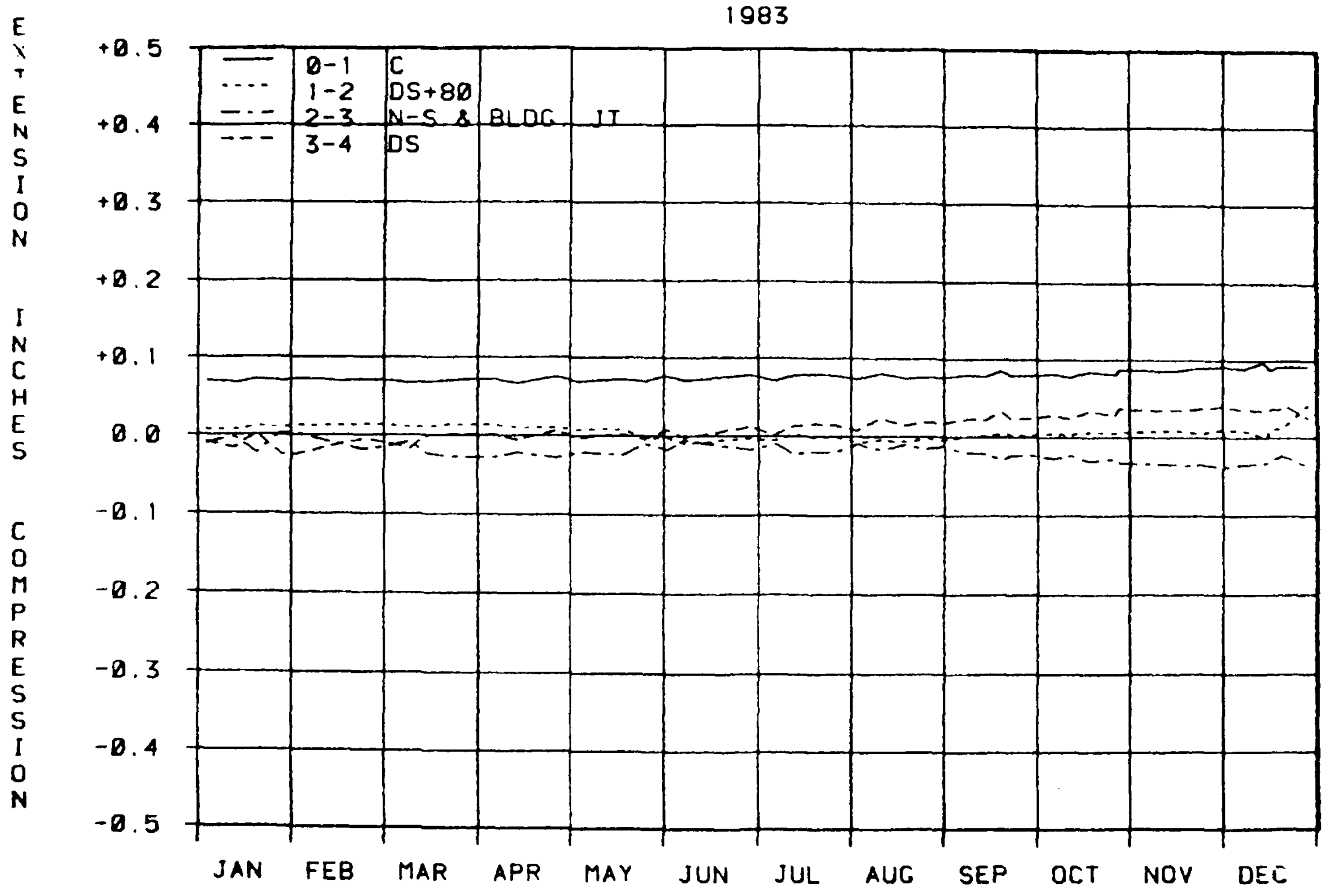
LIBBY LEFT BANK L10 (DELTA DISPLACEMENT)
0-1 C
1-2 DS+80
2-3 N-S & BLDG. JT.
3-4 DS
1968
1969
1970
1971
1972
+0.5
+0.4
+0.3
+0.2
+0.1
0.0
-0.1
-0.2
-0.3
-0.4
-0.5
EXTENSION INCHES COMPRESSION



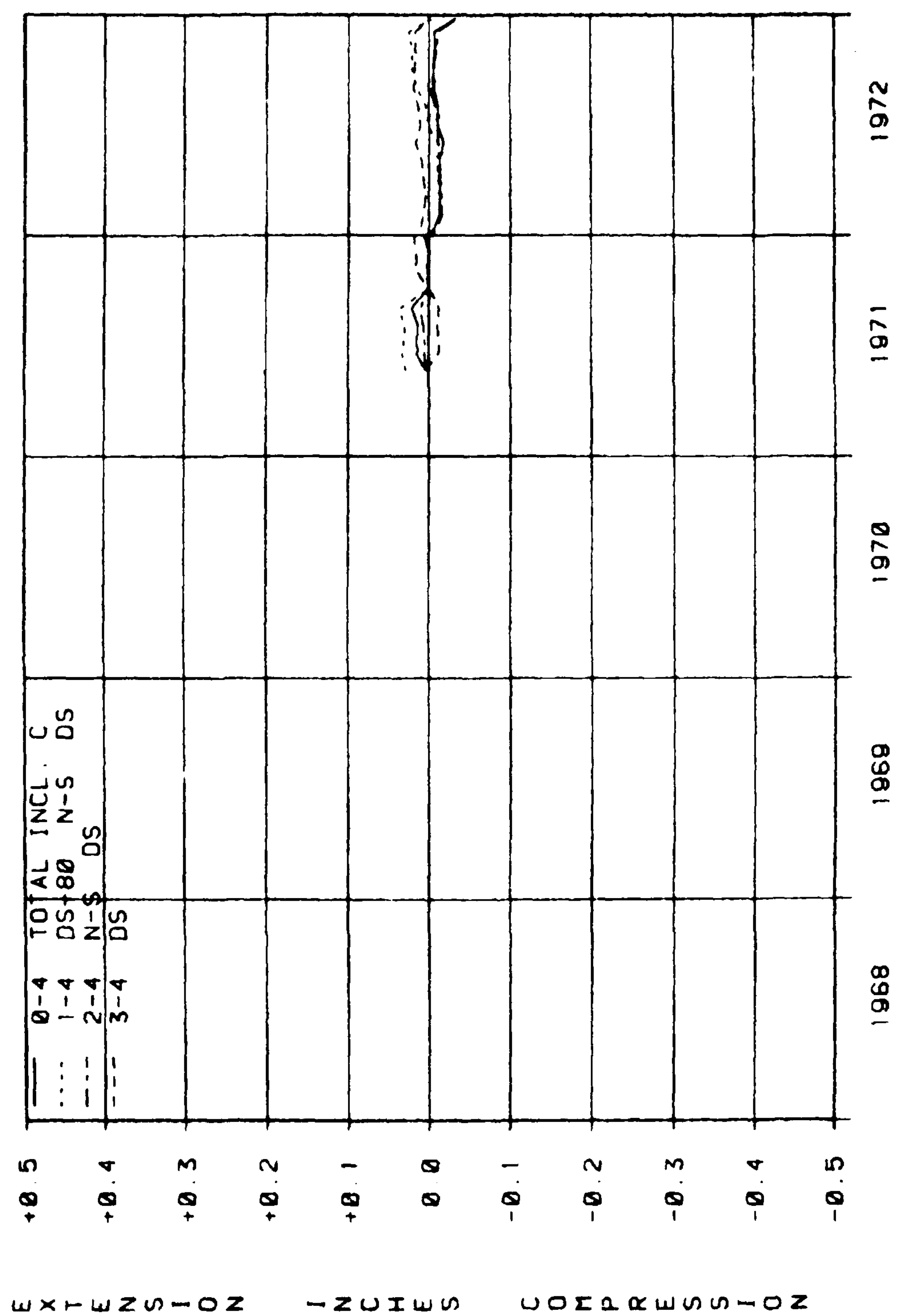
LIBBY LEFT BANK L10 (DELTA DISPLACEMENT)



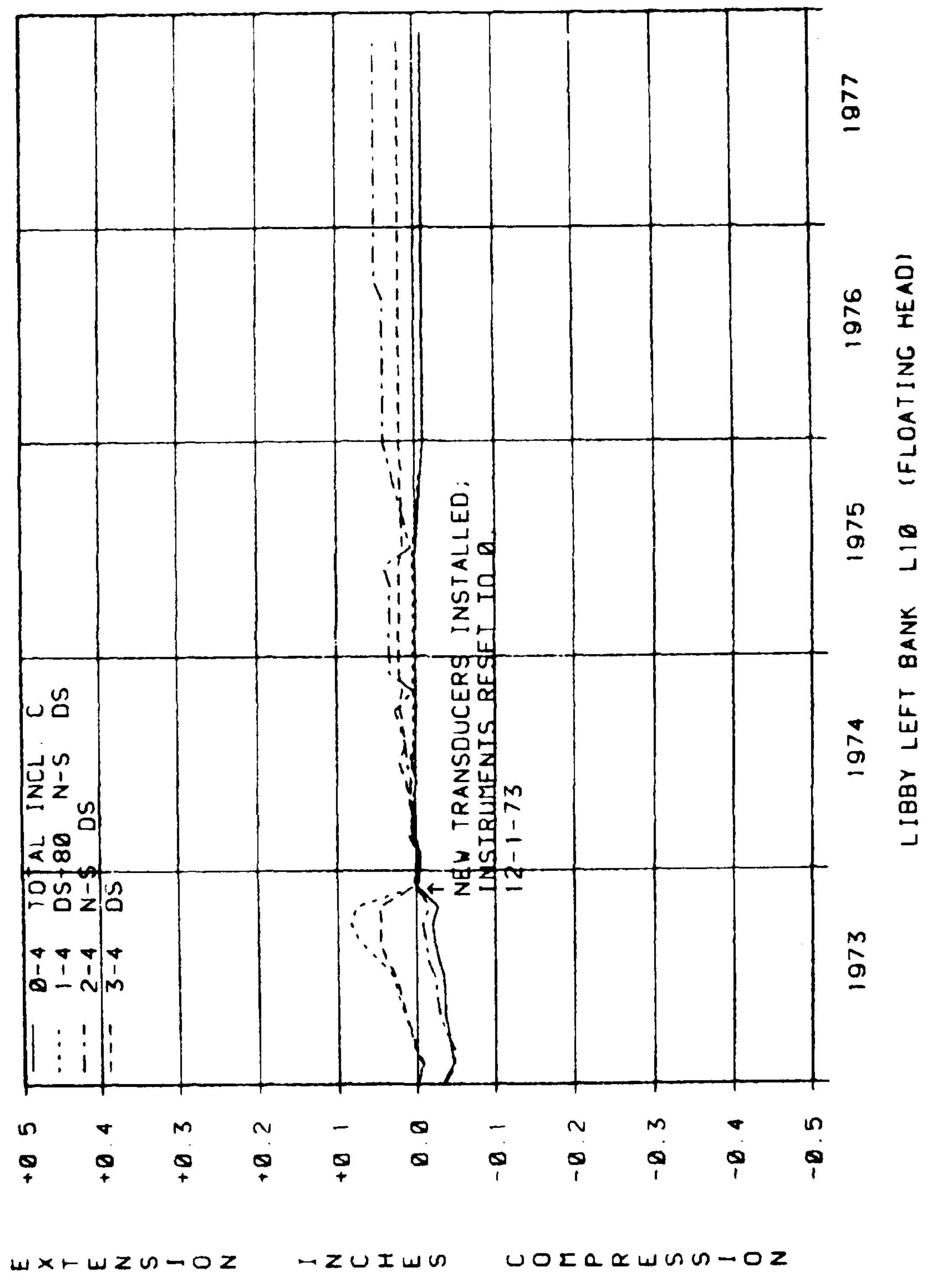
EXTENSION INCHES COMPRESSION
+0.5
+0.4
+0.3
+0.2
+0.1
0.0
-0.1
-0.2
-0.3
-0.4
-0.5
0-1 C
1-2 DS+80
2-3 N-S & BLDG. JT.
3-4 DS
1978
1979
1980
1981
1982
LIBBY LEFT BANK L10 (DELTA DISPLACEMENT)

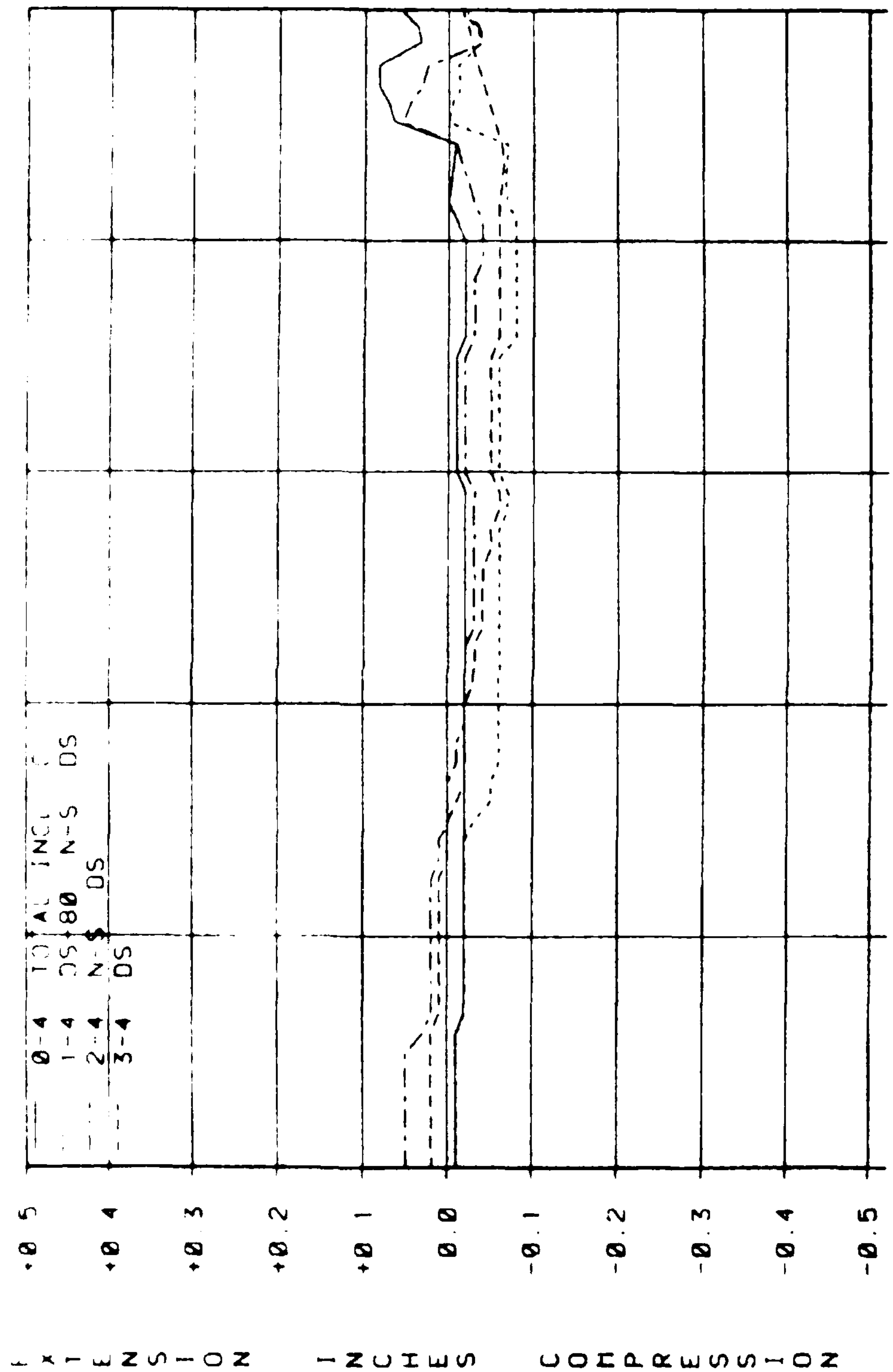


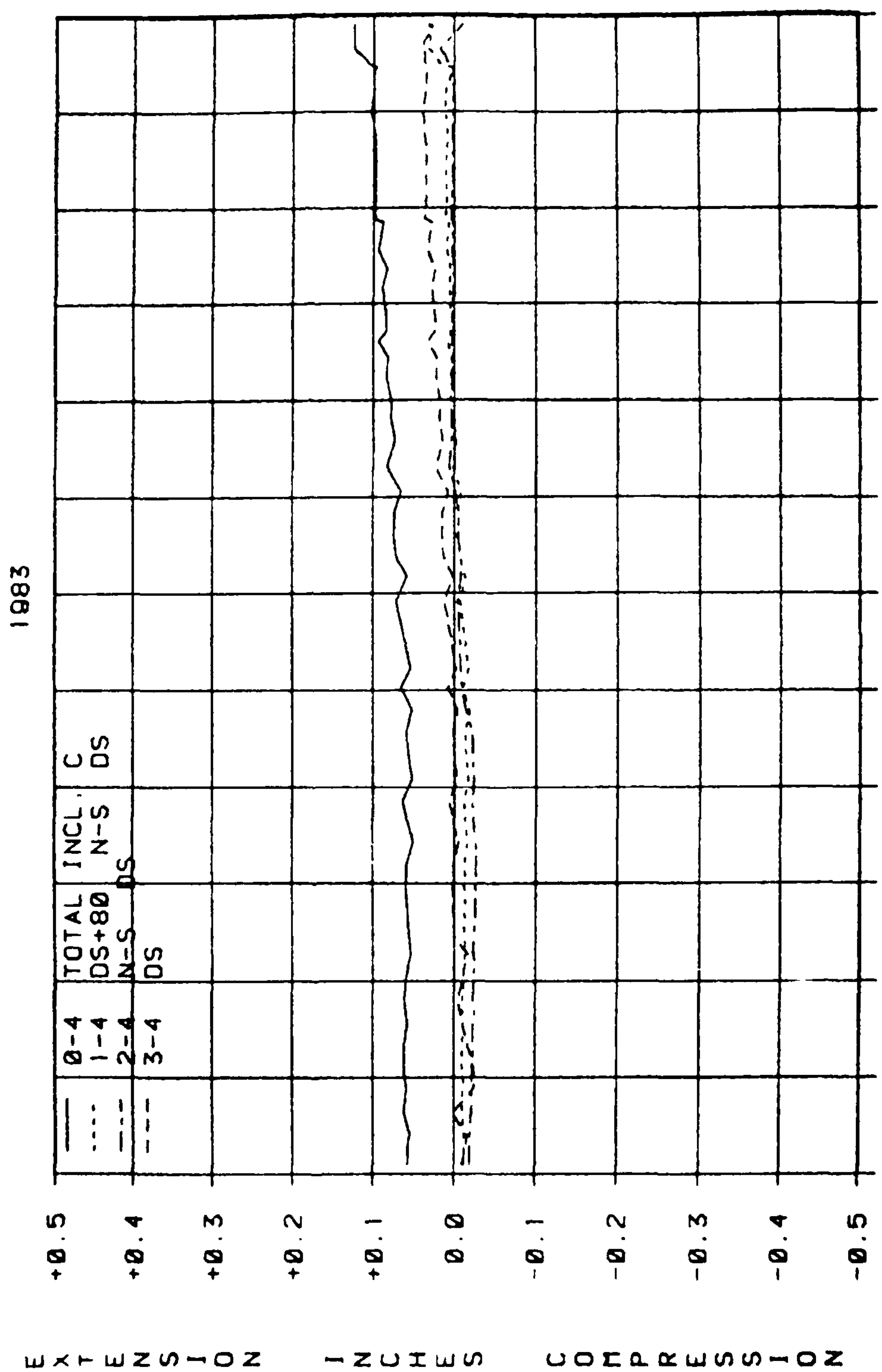
LIBBY LEFT BANK L10 (DELTA DISPLACEMENT)

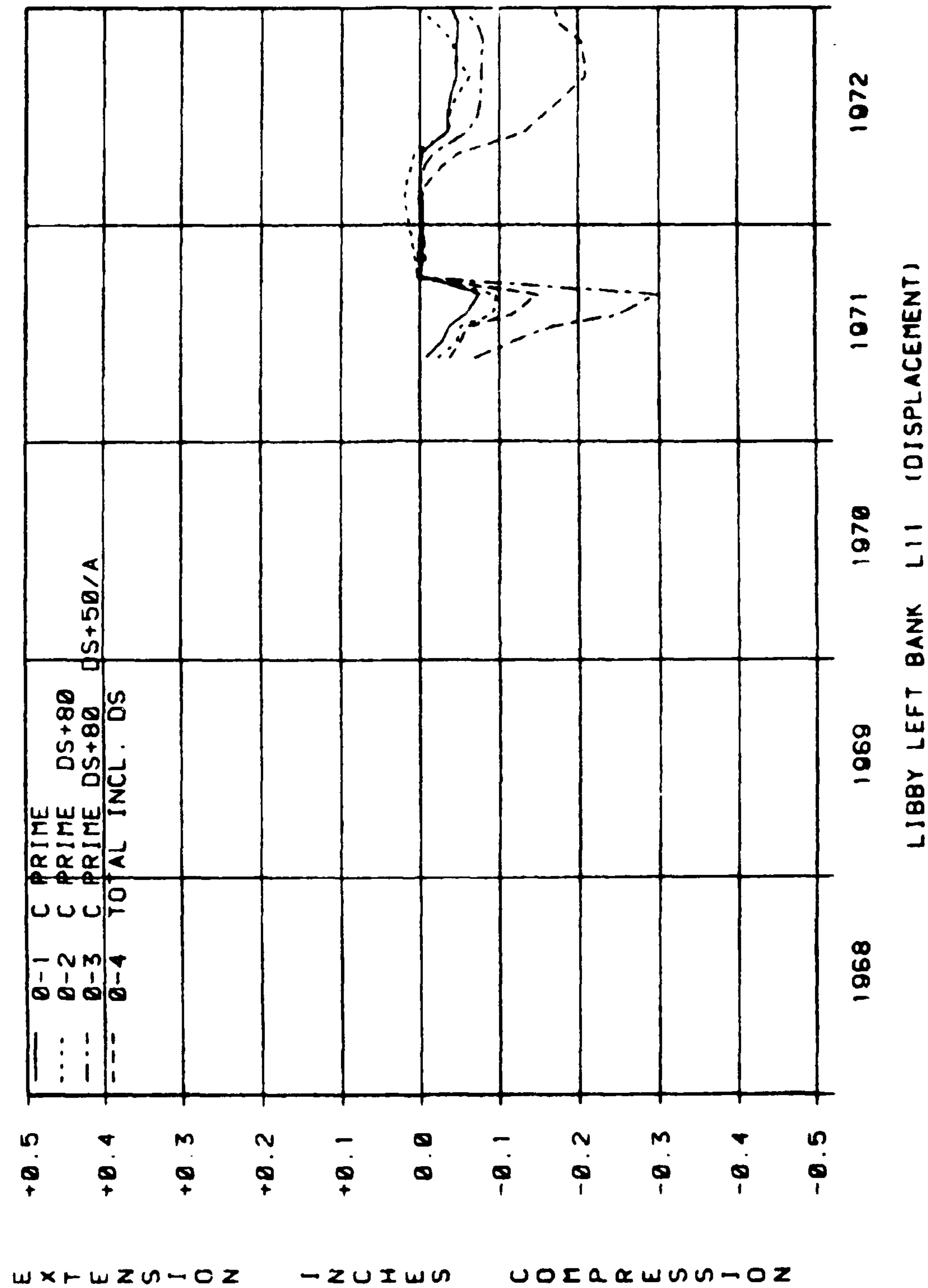


LIBBY LEFT BANK L10 (FLOATING HEAD)

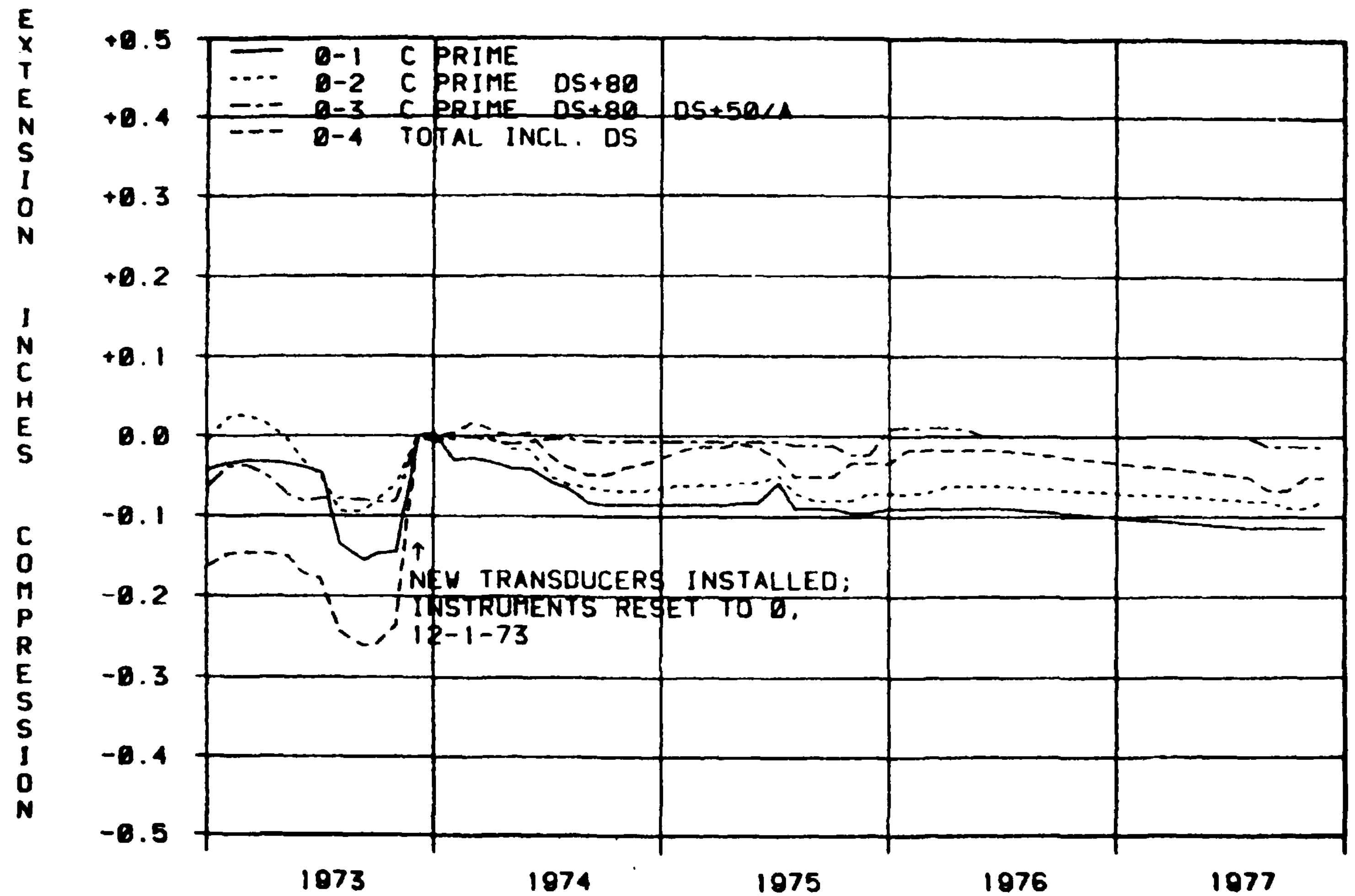

Ø-4 TOTAL INCL C
1-4 DS-80 N-S DS
2-4 N-S DS
3-4 DS
NEW TRANSDUCERS INSTALLED;
INSTRUMENTS RESET TO Ø
12-1-73
+Ø.5
+Ø.4
+Ø.3
+Ø.2
+Ø.1
Ø.Ø
-Ø.1
-Ø.2
-Ø.3
-Ø.4
-Ø.5
EXTENSION INCHES COMPRESSION
1973
1974
1975
1976
1977
LIBBY LEFT BANK L1Ø (FLOATING HEAD)


EXTENSION INCHES COMPRESSION
+0.5
+0.4
+0.3
+0.2
+0.1
0.0
-0.1
-0.2
-0.3
-0.4
-0.5
1978
1979
1980
1981
1982
0-4
1-4
2-4
3-4
DS
N-S DS

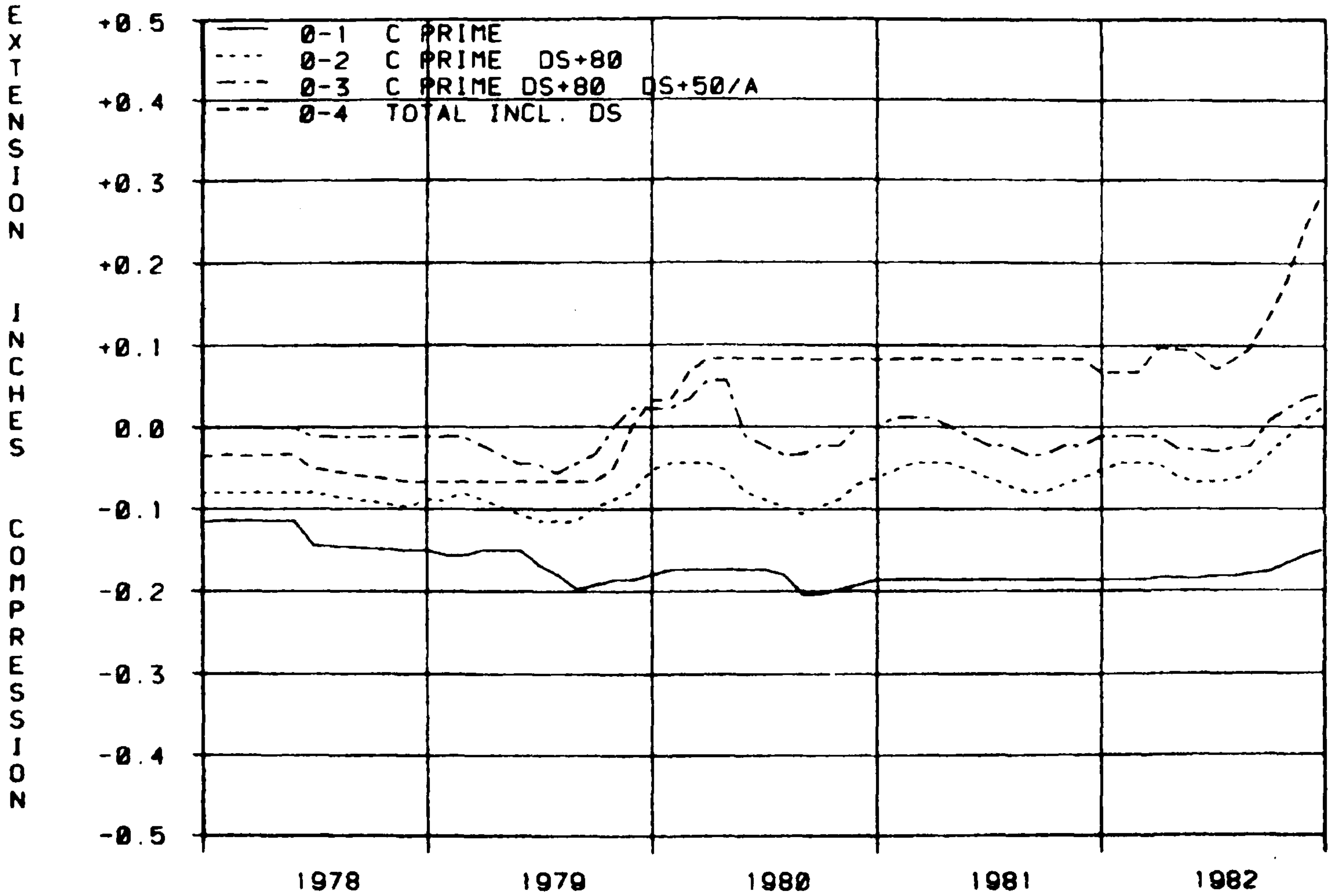

1983
0-4 TOTAL INCL. C
1-4 DS+80 N-S DS
2-4 N-S DS
3-4 DS
+0.5
+0.4
+0.3
+0.2
+0.1
0.0
-0.1
-0.2
-0.3
-0.4
-0.5
EXTENSION INCHES COMPRESSION



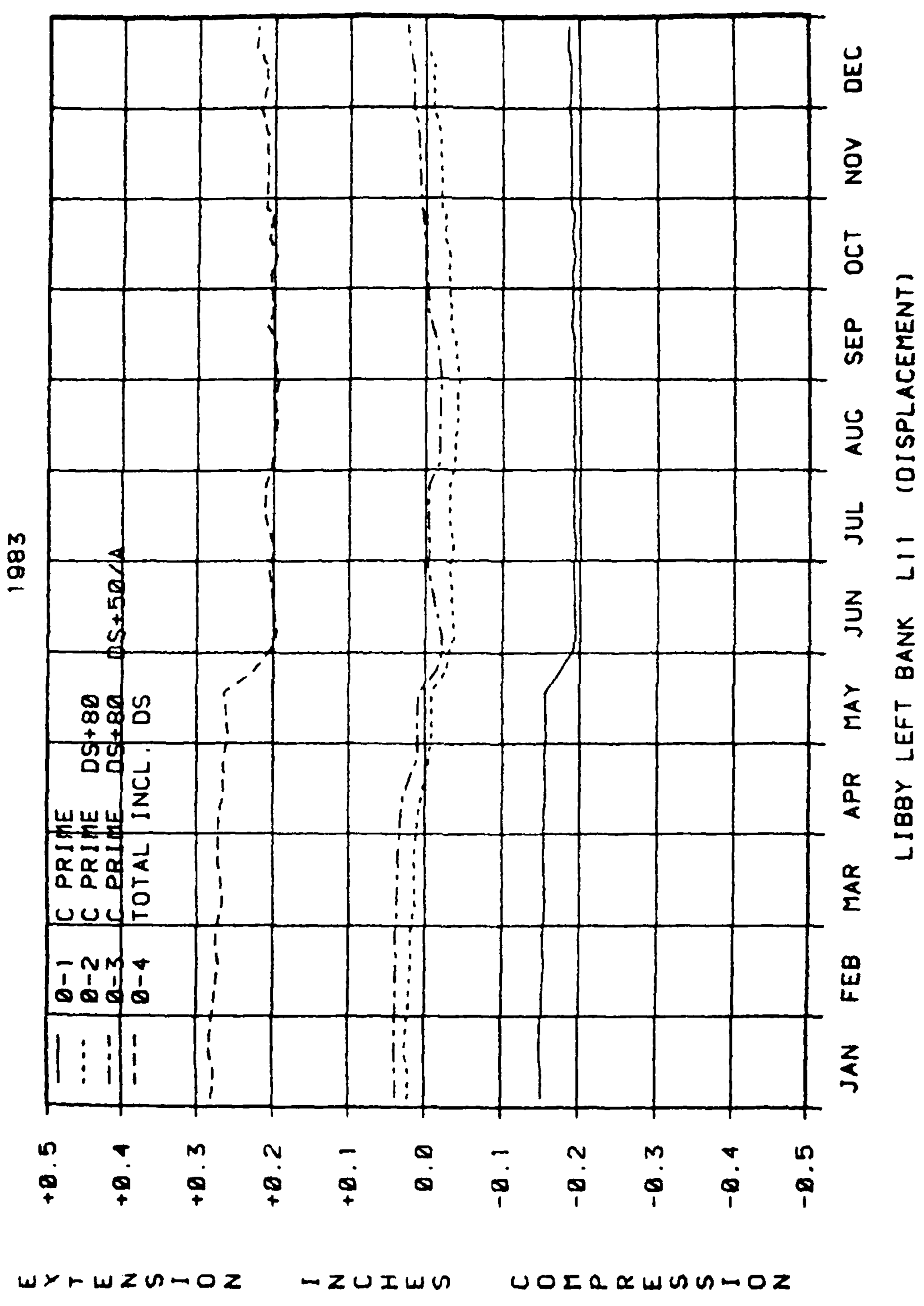
0-1 C PRIME
0-2 C PRIME DS+80
0-3 C PRIME DS+80 DS+50/A
0-4 TOTAL INCL. DS
+0.5
+0.4
+0.3
+0.2
+0.1
0.0
-0.1
-0.2
-0.3
-0.4
-0.5
EXTENSION INCHES COMPRESSION
1968
1969
1970
1971
1972
LIBBY LEFT BANK L11 (DISPLACEMENT)

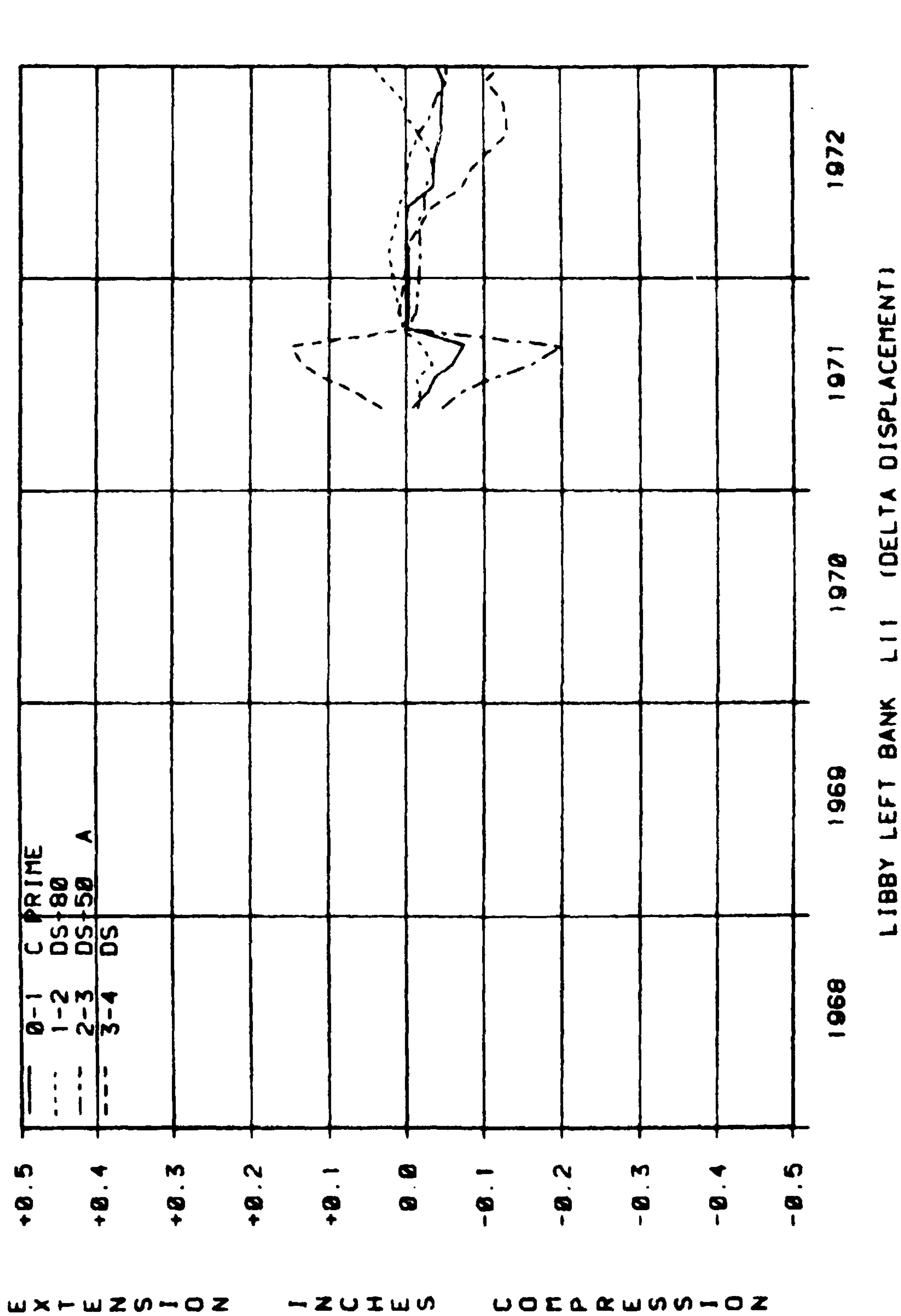


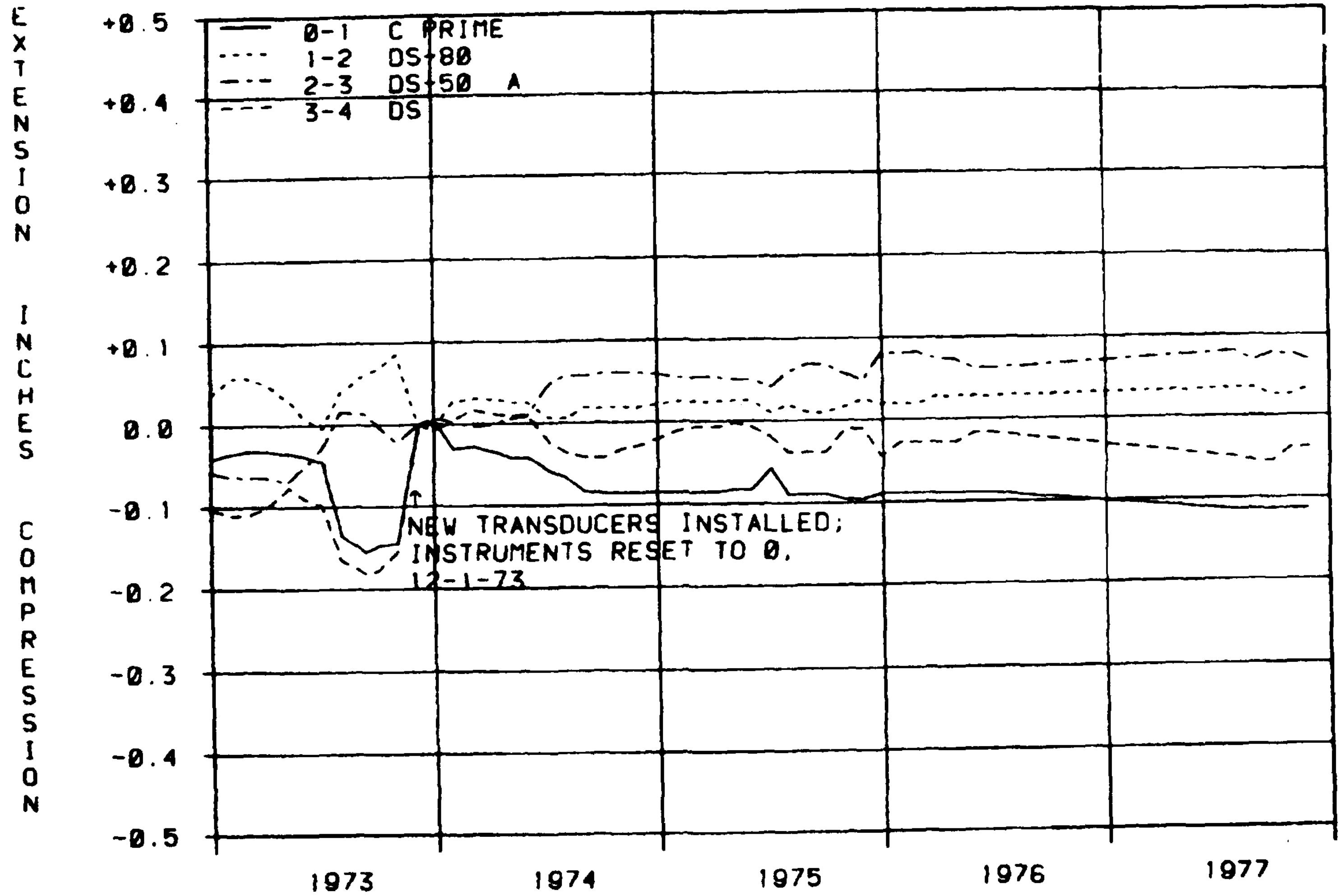
LIBBY LEFT BANK L11 (DISPLACEMENT)



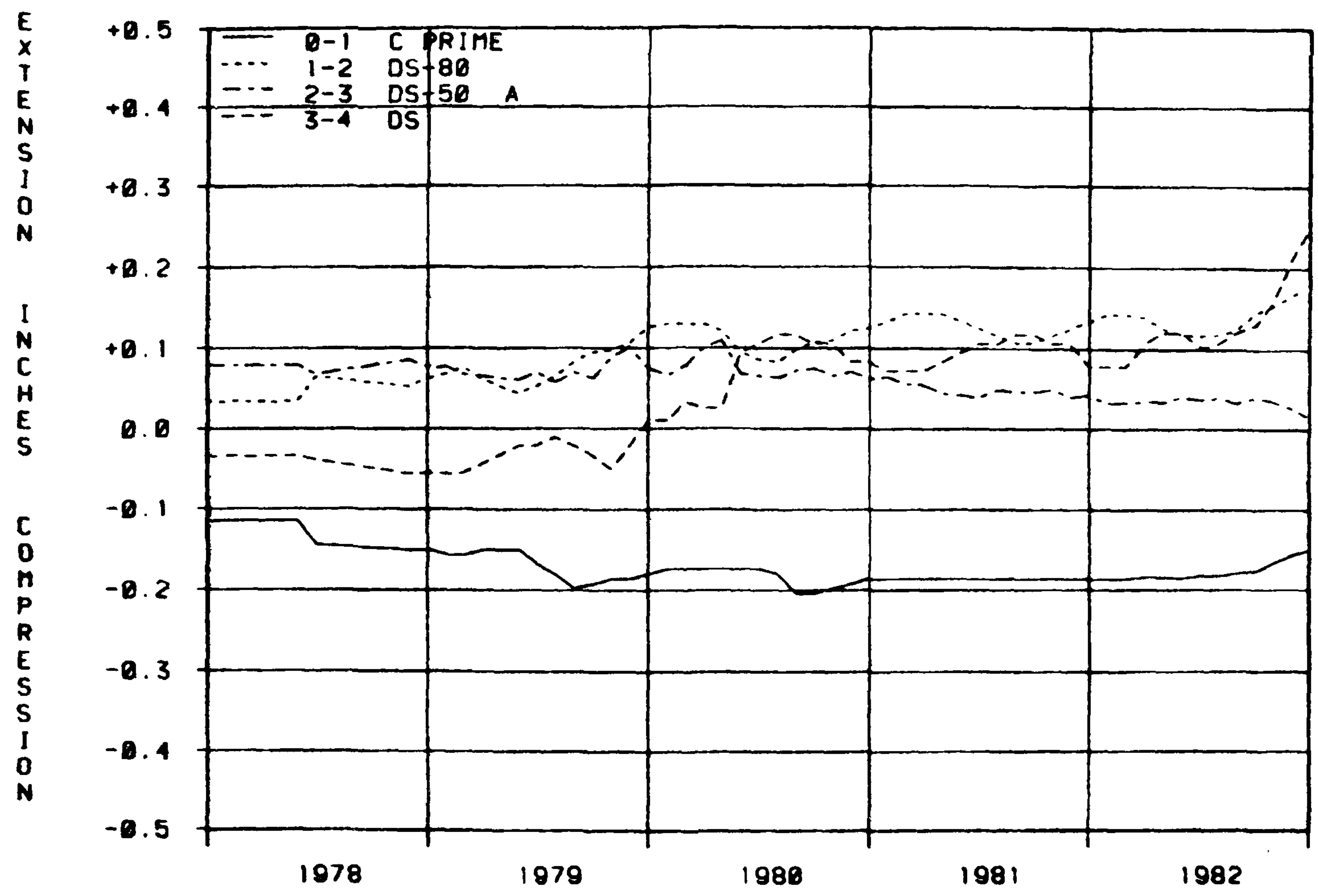
LIBBY LEFT BANK L11 (DISPLACEMENT)


1983
0-1 C PRIME
0-2 C PRIME DS+80
0-3 C PRIME DS+80 DS+50/A
0-4 TOTAL INCL. DS
JAN FEB MAR APR MAY JUN JUL AUG SEP OCT NOV DEC
LIBBY LEFT BANK L11 (DISPLACEMENT)
+0.5 +0.4 +0.3 +0.2 +0.1 0.0 -0.1 -0.2 -0.3 -0.4 -0.5
EXTENSION INCHES COMPRESSION

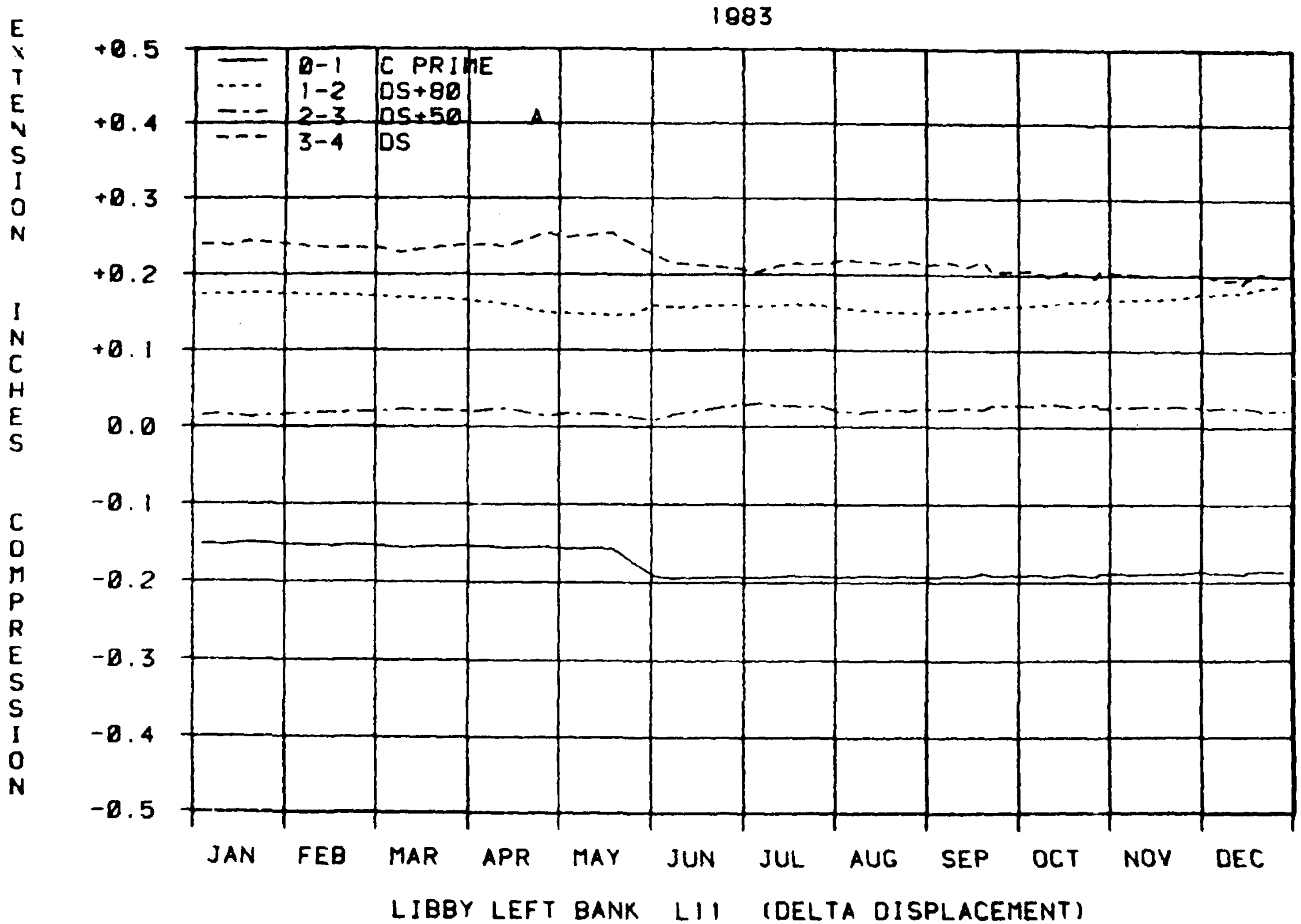

0-1 C PRIME
1-2 DS-80
2-3 DS-50 A
3-4 DS
+0.5
+0.4
+0.3
+0.2
+0.1
0.0
-0.1
-0.2
-0.3
-0.4
-0.5
EXTENSION INCHES COMPRESSION
1968
1969
1970
1971
1972
LIBBY LEFT BANK L11 (DELTA DISPLACEMENT)



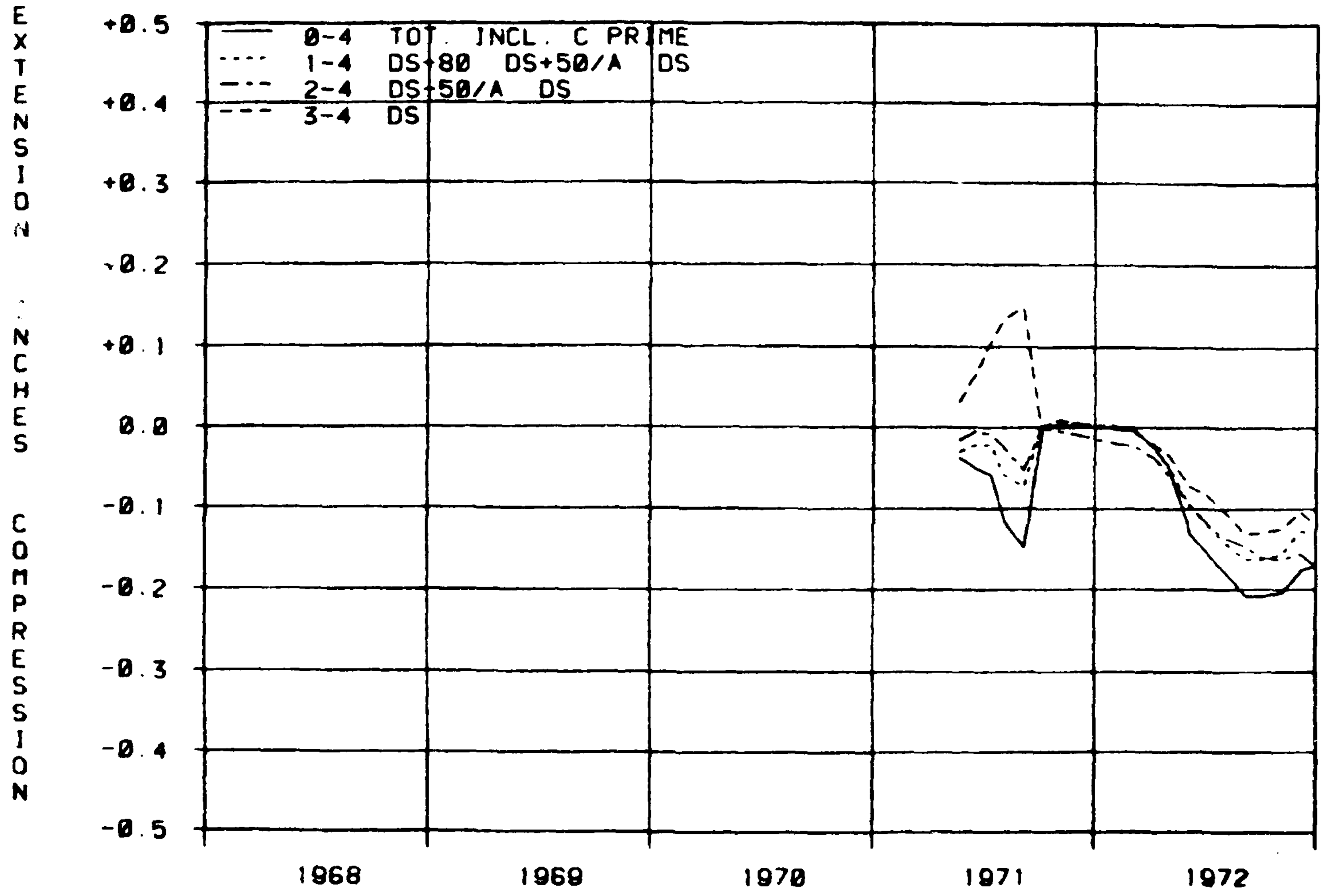
LIBBY LEFT BANK L11 (DELTA DISPLACEMENT)



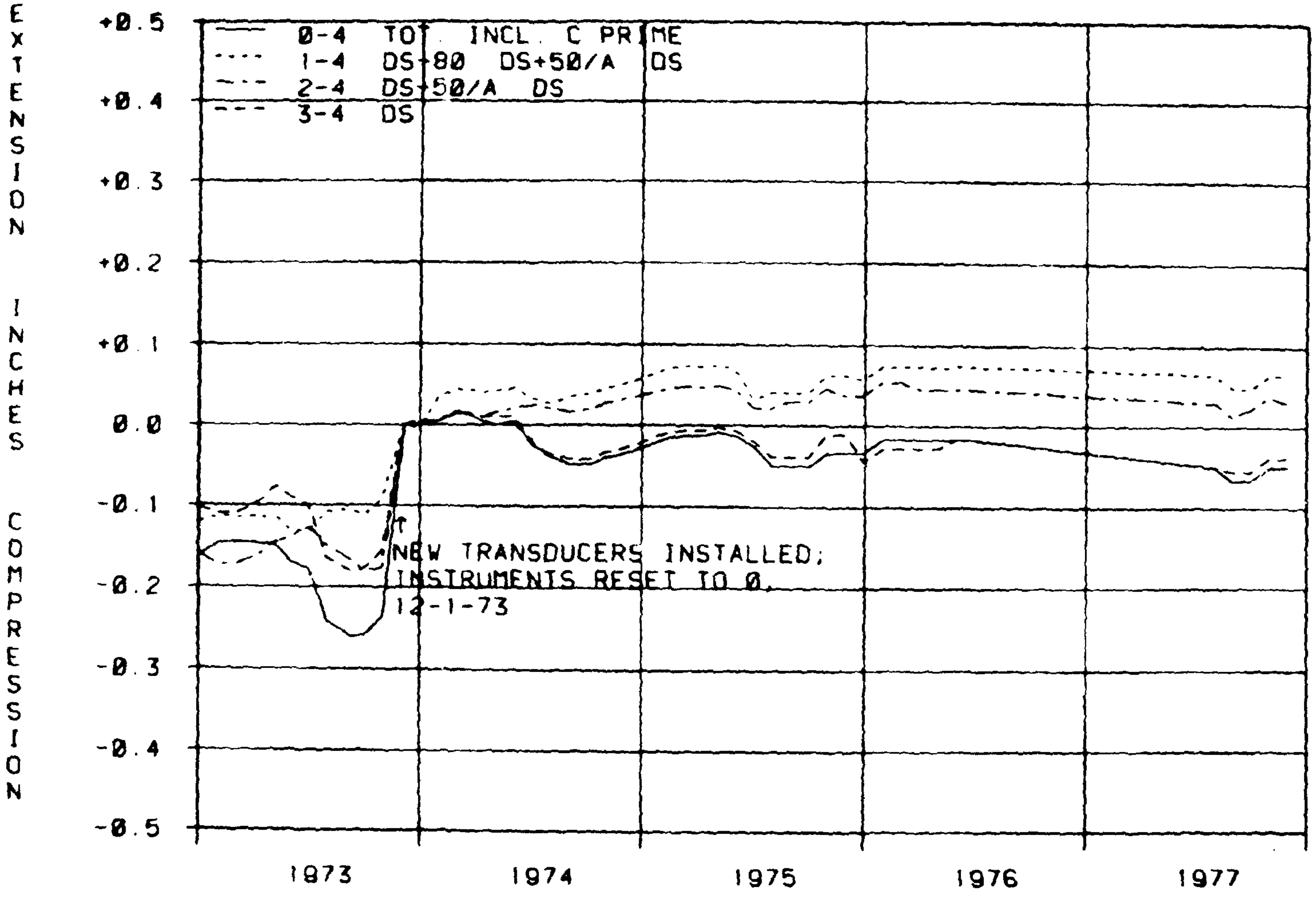
LIBBY LEFT BANK L11 (DELTA DISPLACEMENT)



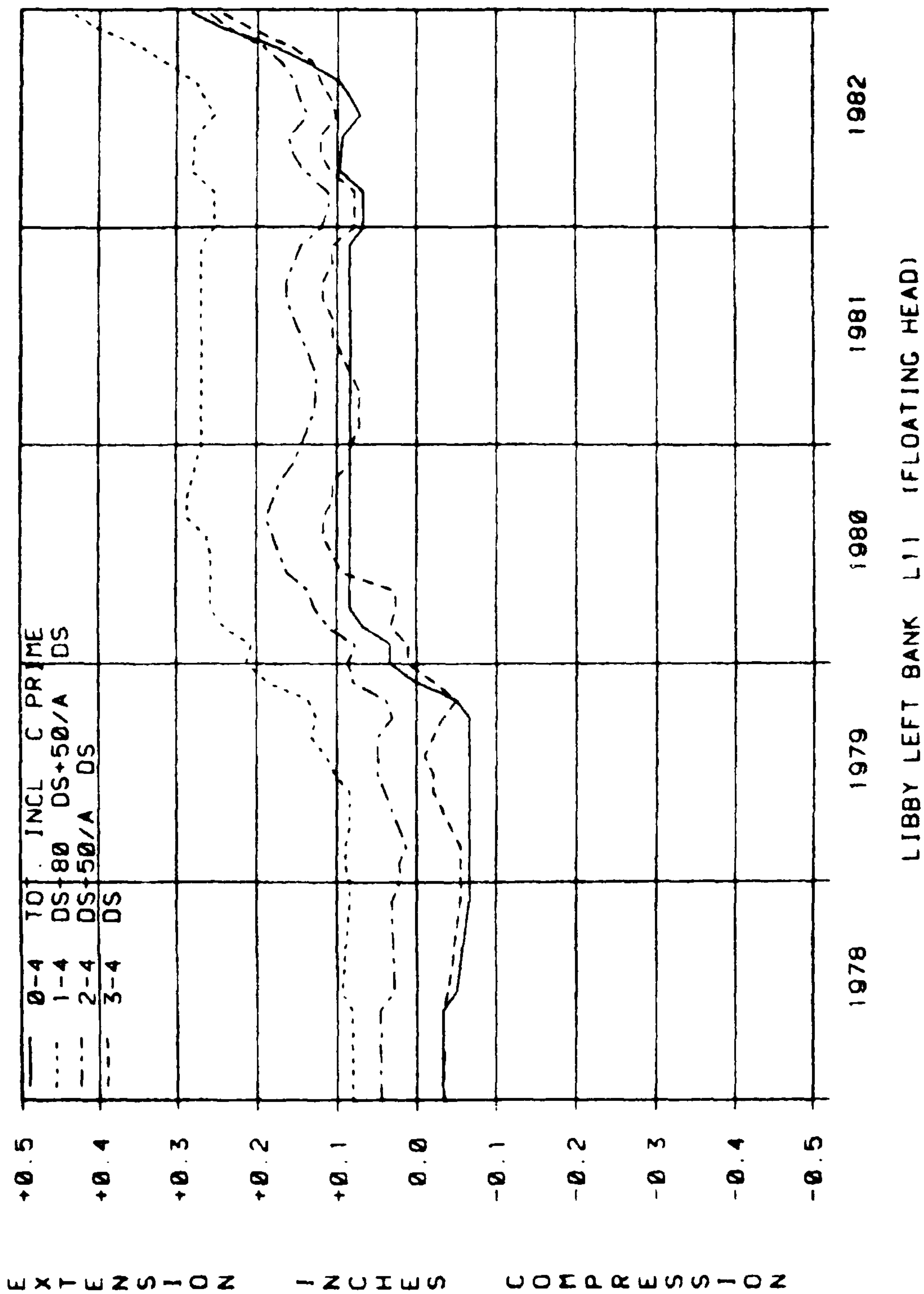
1983
0-1 C PRIME
1-2 DS+80
2-3 DS+50
3-4 DS
A
+0.5
+0.4
+0.3
+0.2
+0.1
0.0
-0.1
-0.2
-0.3
-0.4
-0.5
EXTENSION INCHES COMPRESSION
JAN FEB MAR APR MAY JUN JUL AUG SEP OCT NOV DEC
LIBBY LEFT BANK L11 (DELTA DISPLACEMENT)

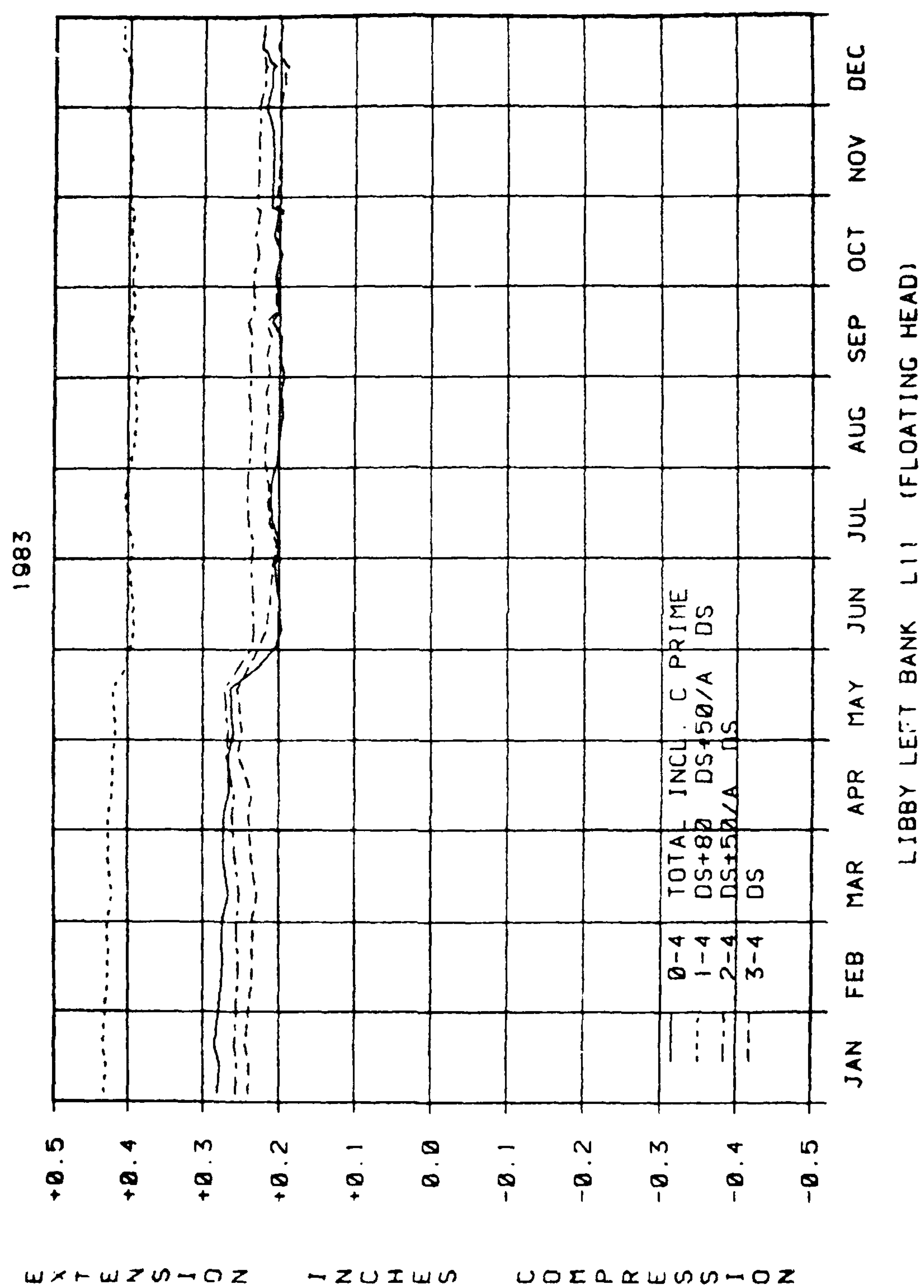


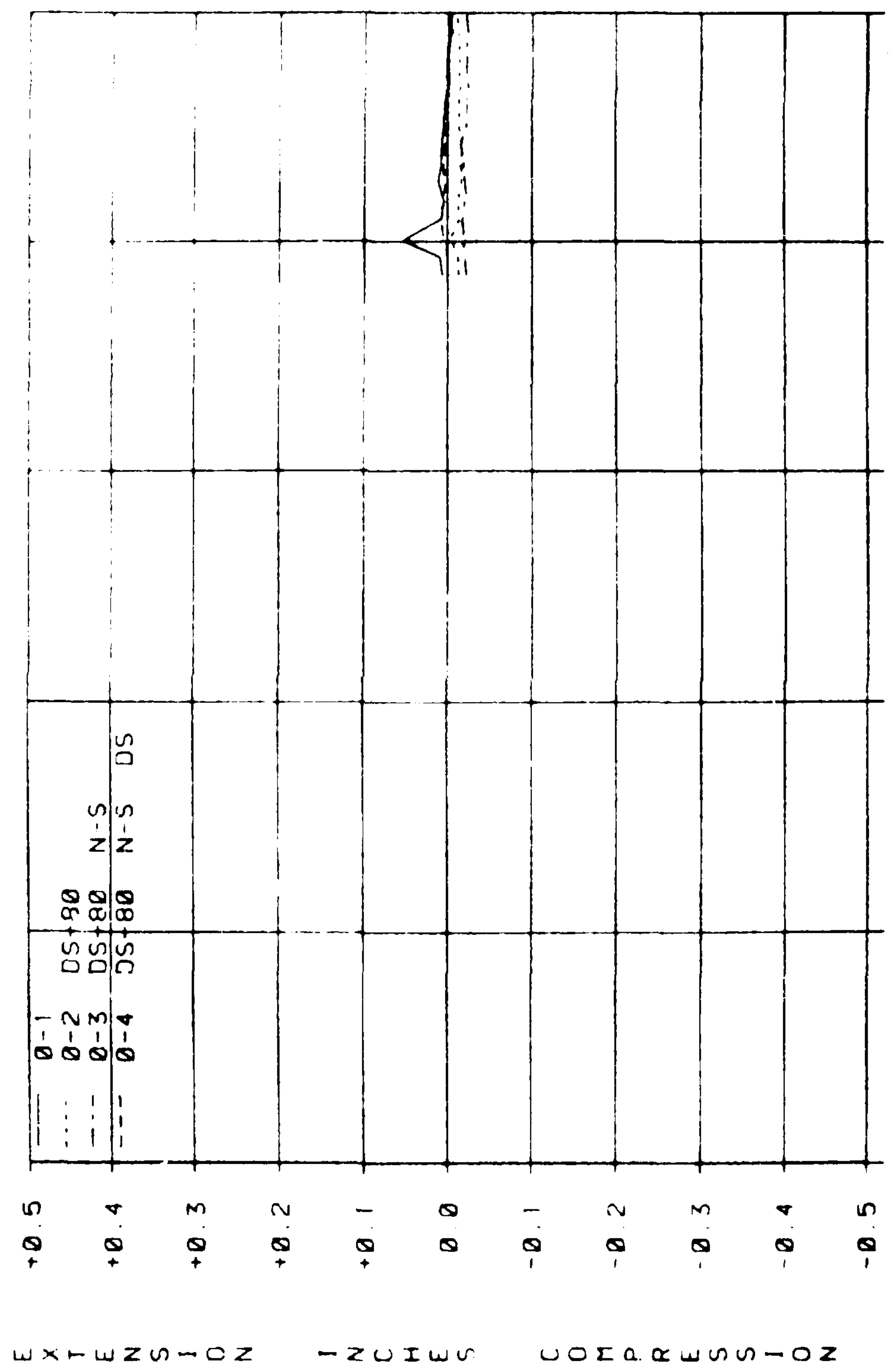
LIBBY LEFT BANK L11 (FLOATING HEAD)

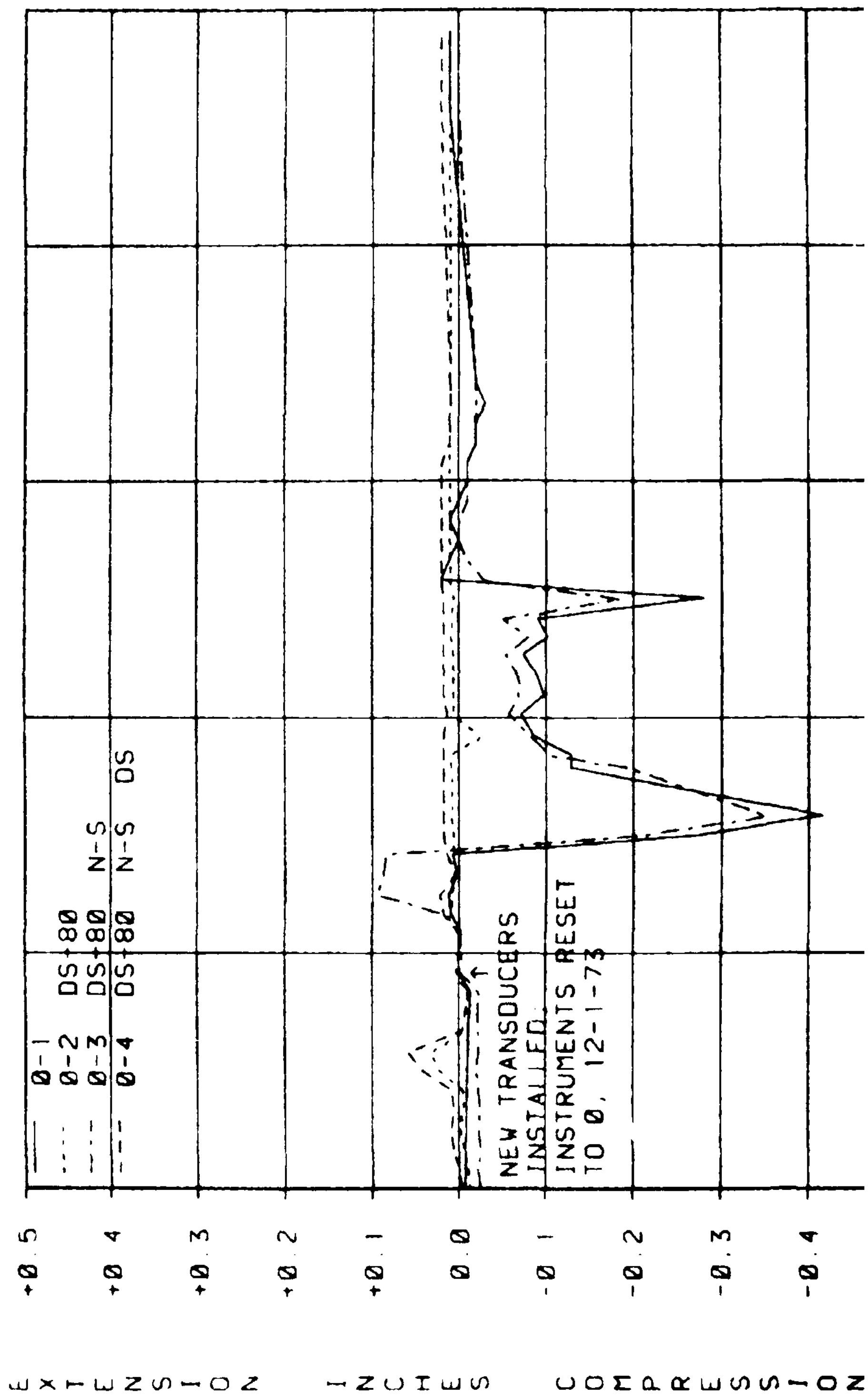


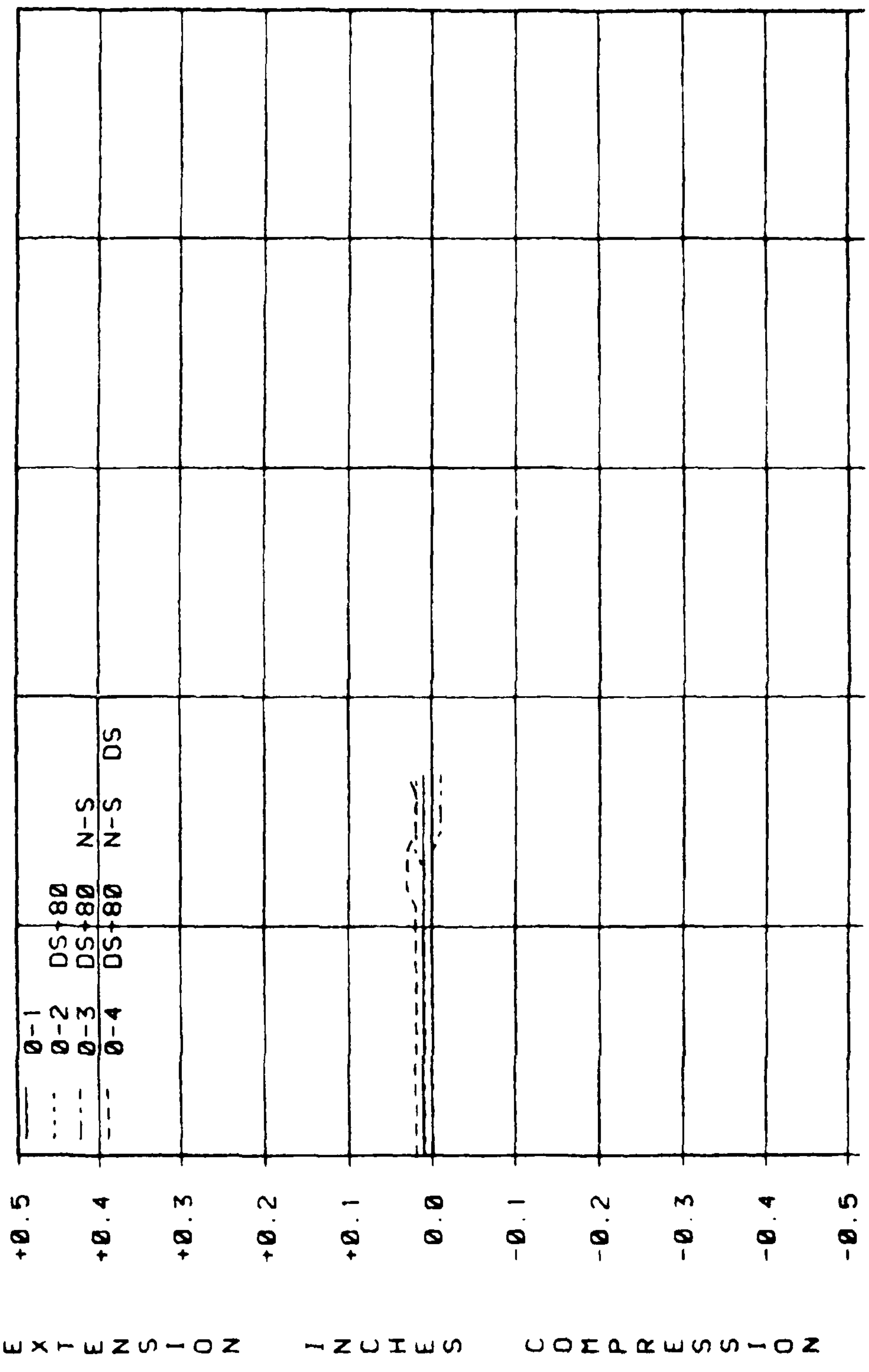
LIBBY LEFT BANK L11 (FLOATING HEAD)


0-4 TOT. INCL C PRIME
1-4 DS-80 DS+50/A DS
2-4 DS-50/A DS
3-4 DS
+0.5
+0.4
+0.3
+0.2
+0.1
0.0
-0.1
-0.2
-0.3
-0.4
-0.5
EXTENSION INCHES COMPRESSION
1978
1979
1980
1981
1982
LIBBY LEFT BANK L11 (FLOATING HEAD)

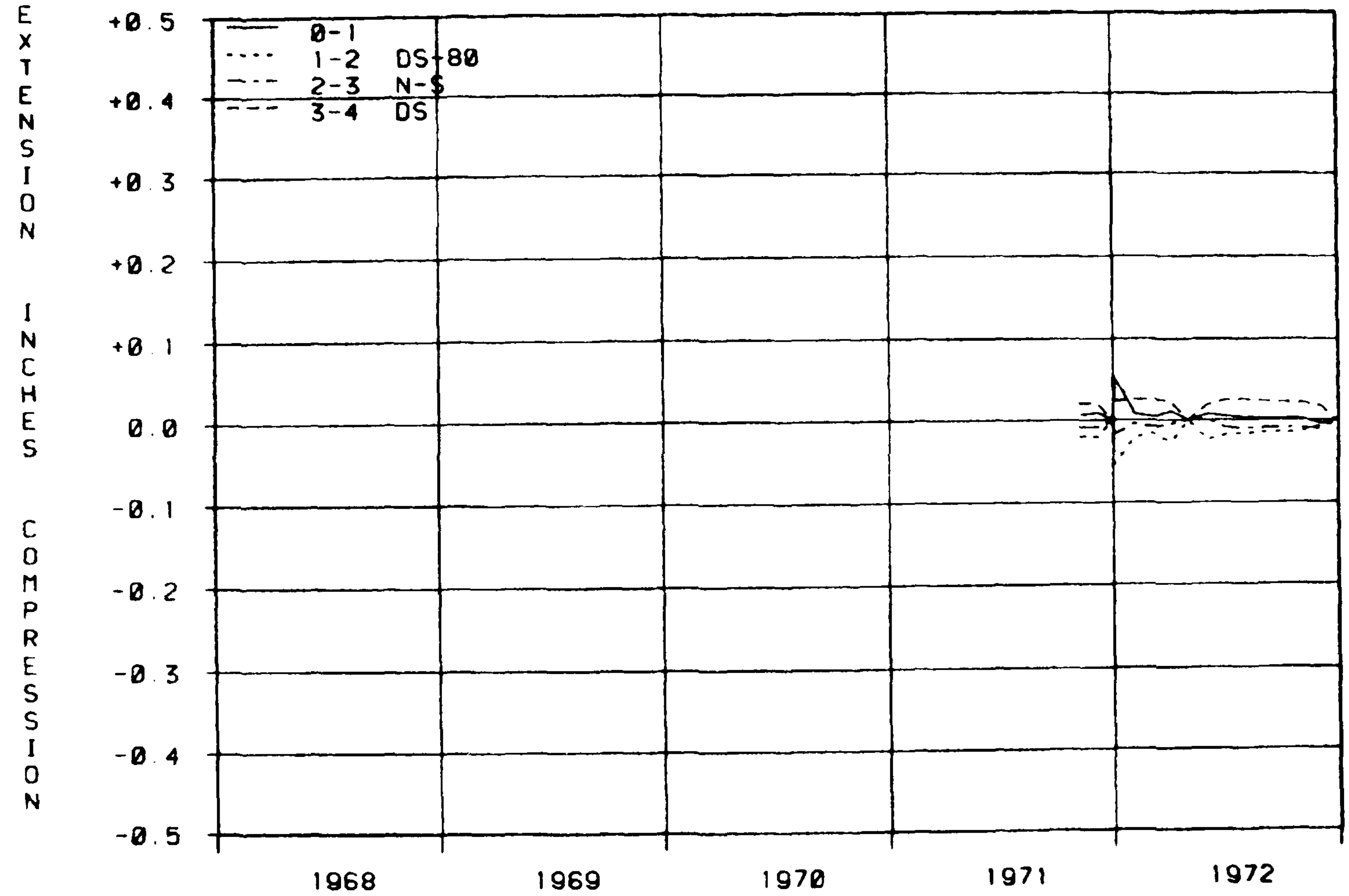

1983
0-4 TOTAL INCL. C PRIME
1-4 DS+80 DS+50/A DS
2-4 DS+50/A DS
3-4 DS
+0.5
+0.4
+0.3
+0.2
+0.1
0.0
-0.1
-0.2
-0.3
-0.4
-0.5
EXTENSION INCHES COMPRESSION
JAN FEB MAR APR MAY JUN JUL AUG SEP OCT NOV DEC
LIBBY LEFT BANK L11 (FLOATING HEAD)


Ø-1
Ø-2 DS+80
Ø-3 DS+80 N-S
Ø-4 DS+80 N-S DS
1968
1969
1970
1971
1972
+0.5
+0.4
+0.3
+0.2
+0.1
0.0
-0.1
-0.2
-0.3
-0.4
-0.5
EXTENSION
INCHES
COMPRESSION

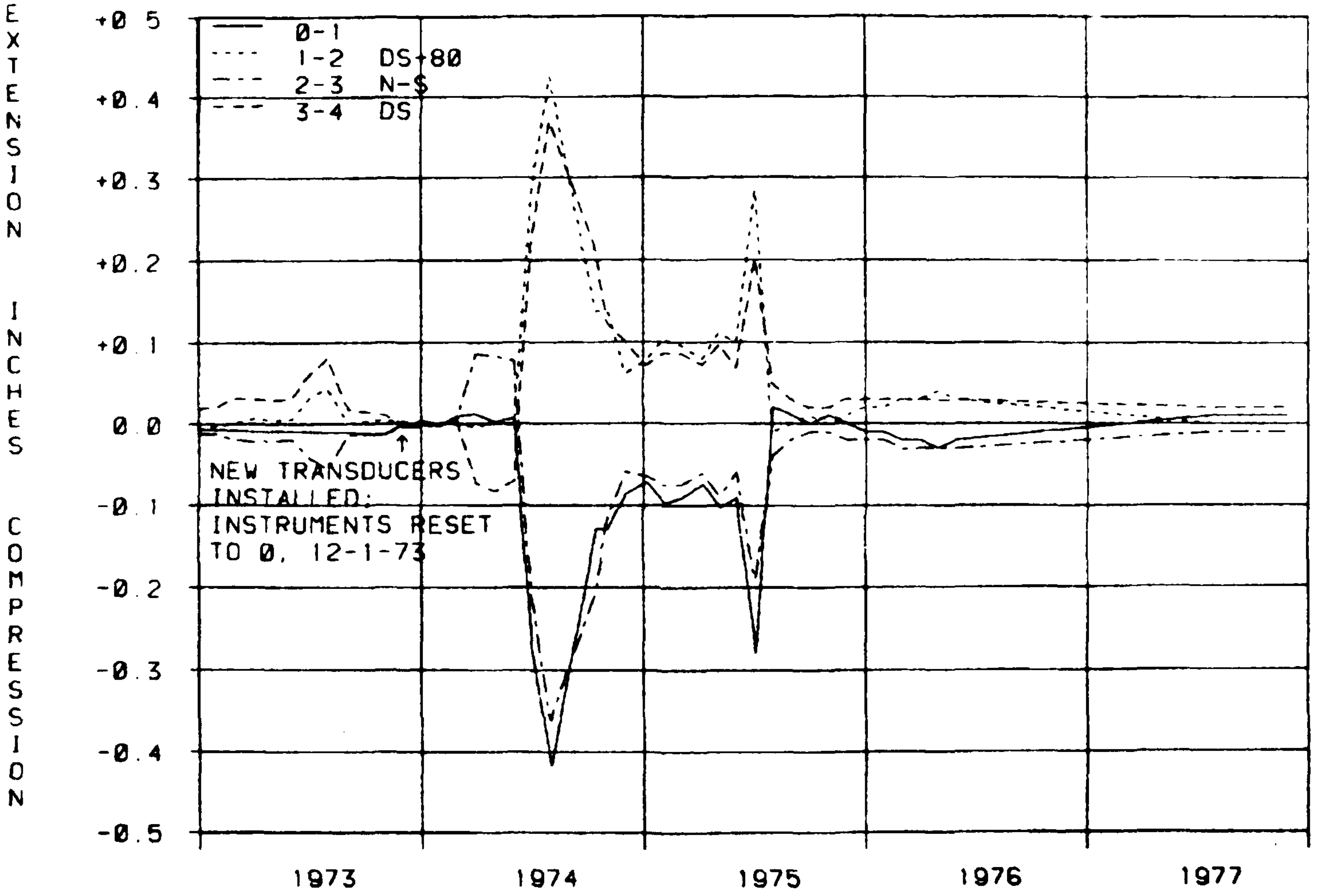

Ø-1
Ø-2 DS-80
Ø-3 DS-80 N-S
Ø-4 DS-80 N-S DS
NEW TRANSDUCERS INSTALLED
INSTRUMENTS RESET TO Ø, 12-1-73
+Ø.5
+Ø.4
+Ø.3
+Ø.2
+Ø.1
Ø.Ø
-Ø.1
-Ø.2
-Ø.3
-Ø.4
EXTENSION
INCHES
COMPRESSION



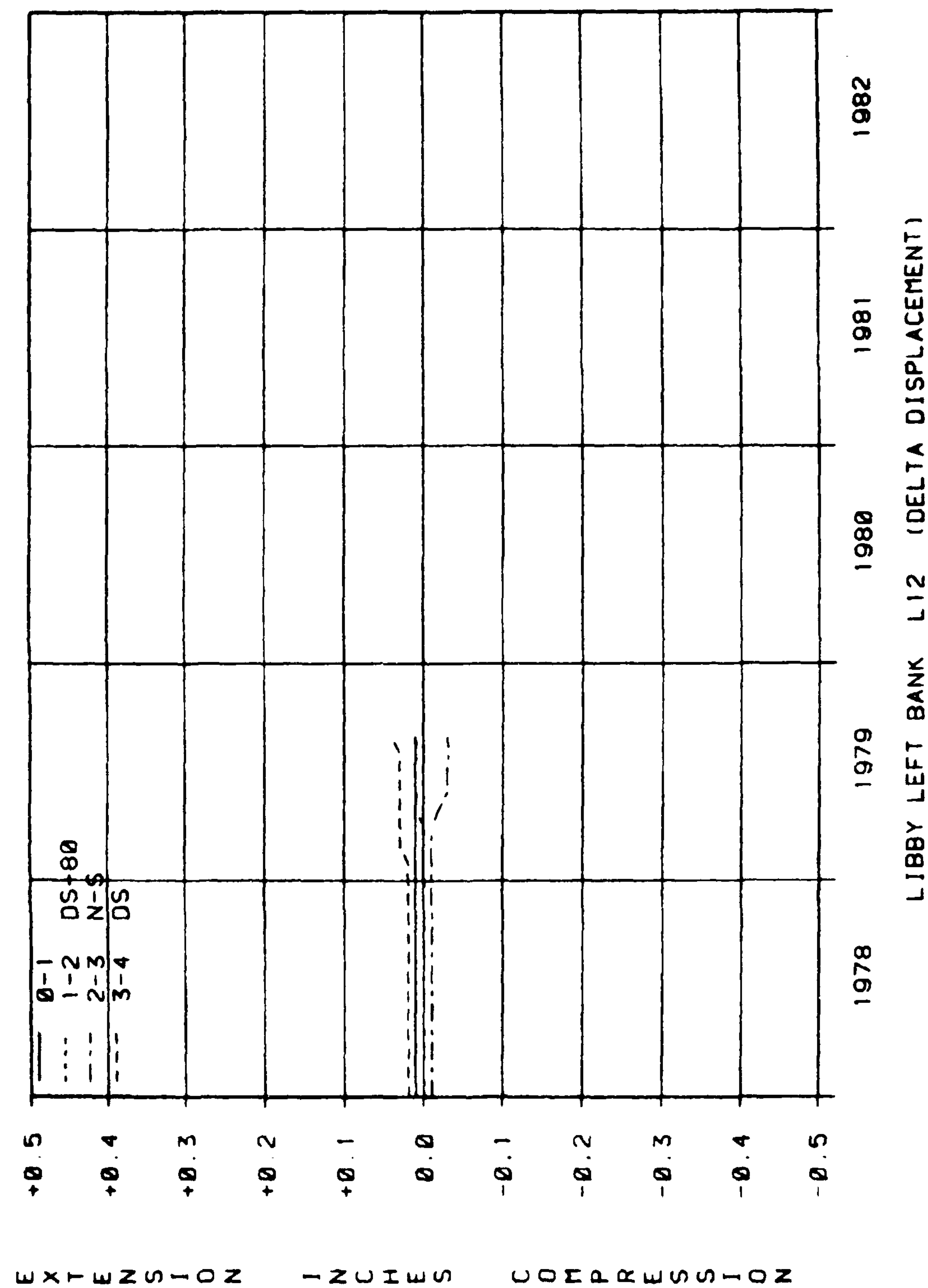
Ø-1
Ø-2 DS+8Ø
Ø-3 DS+8Ø N-S
Ø-4 DS+8Ø N-S DS
+Ø.5
+Ø.4
+Ø.3
+Ø.2
+Ø.1
Ø.Ø
-Ø.1
-Ø.2
-Ø.3
-Ø.4
-Ø.5
EXTENSION INCHES COMPRESSION

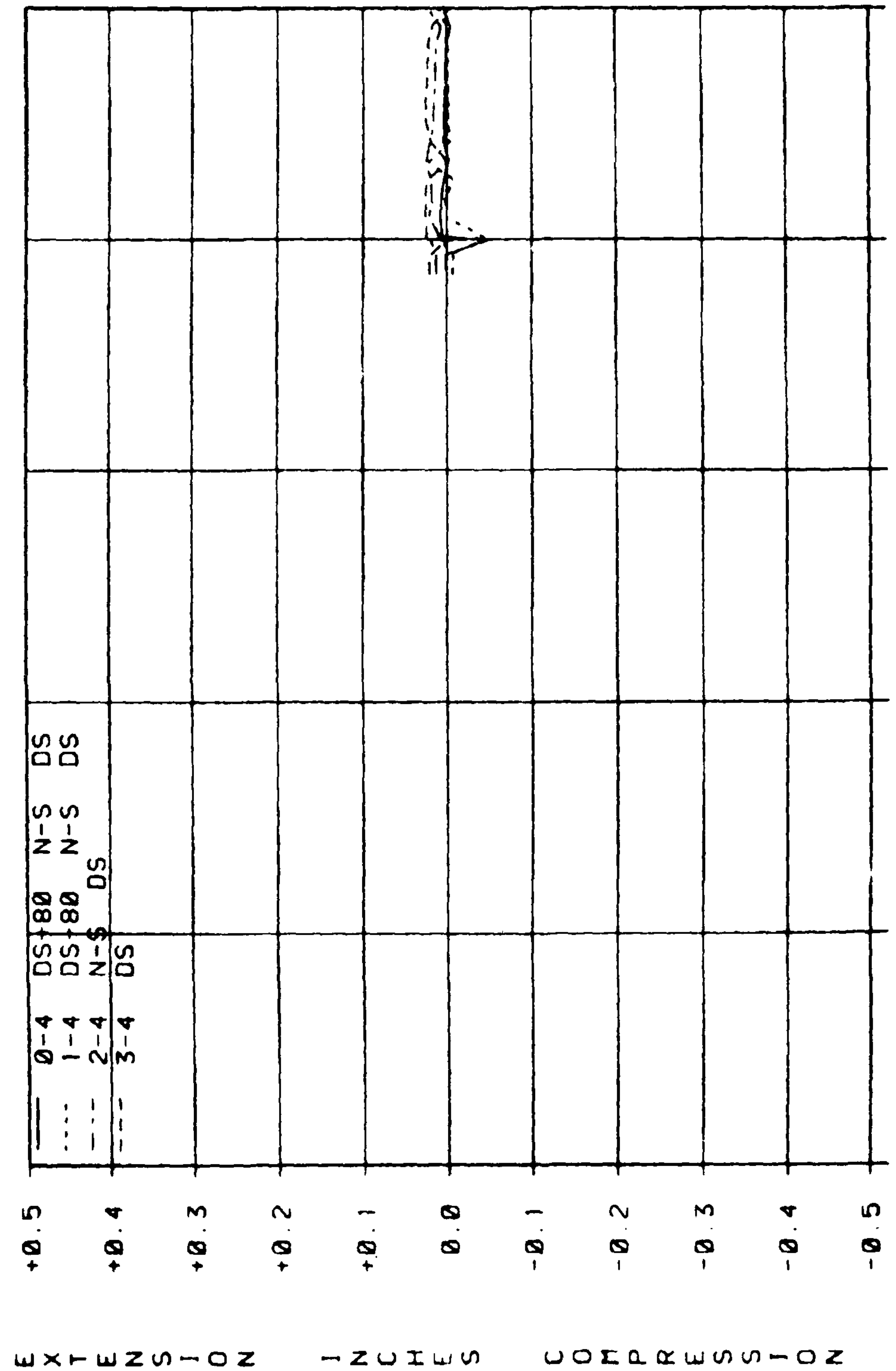


LIBBY LEFT BANK L12 (DELTA DISPLACEMENT)

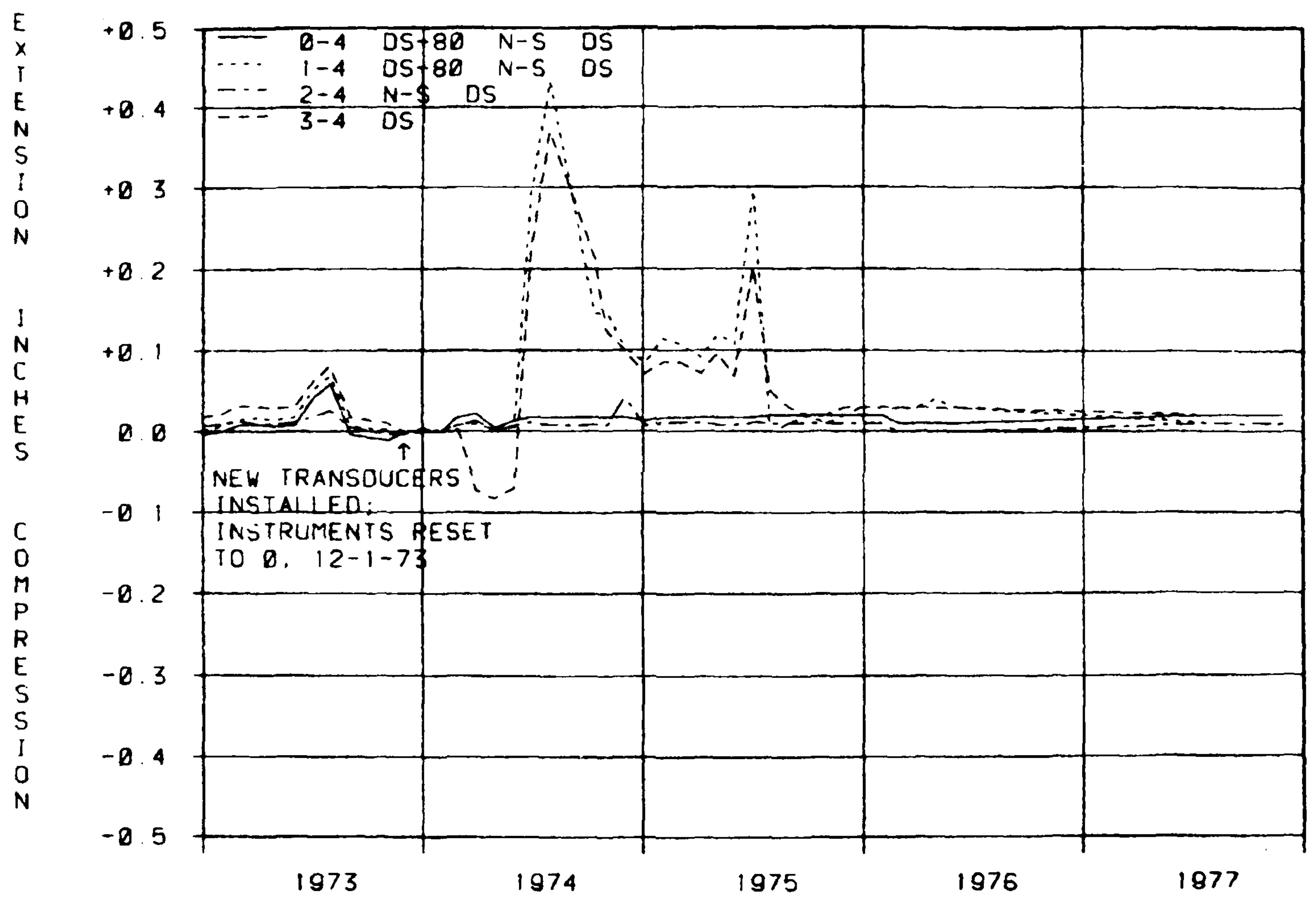


LIBBY LEFT BANK L12 (DELTA DISPLACEMENT)

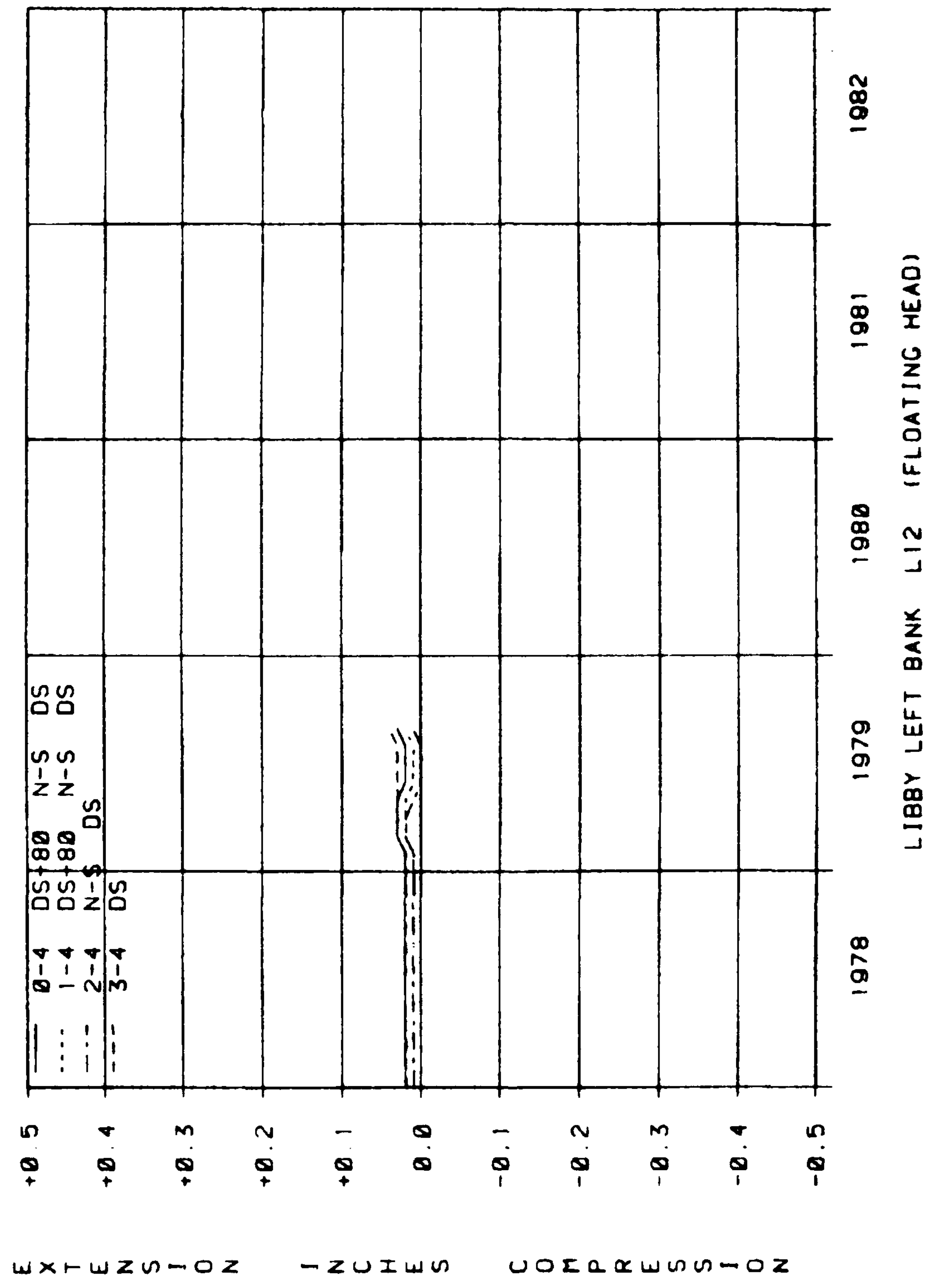

LIBBY LEFT BANK L12 (DELTA DISPLACEMENT)
1978
1979
1980
1981
1982
+0.5
+0.4
+0.3
+0.2
+0.1
0.0
-0.1
-0.2
-0.3
-0.4
-0.5
EXTENSION INCHES COMPRESSION
0-1
1-2 DS+80
2-3 N-S
3-4 DS



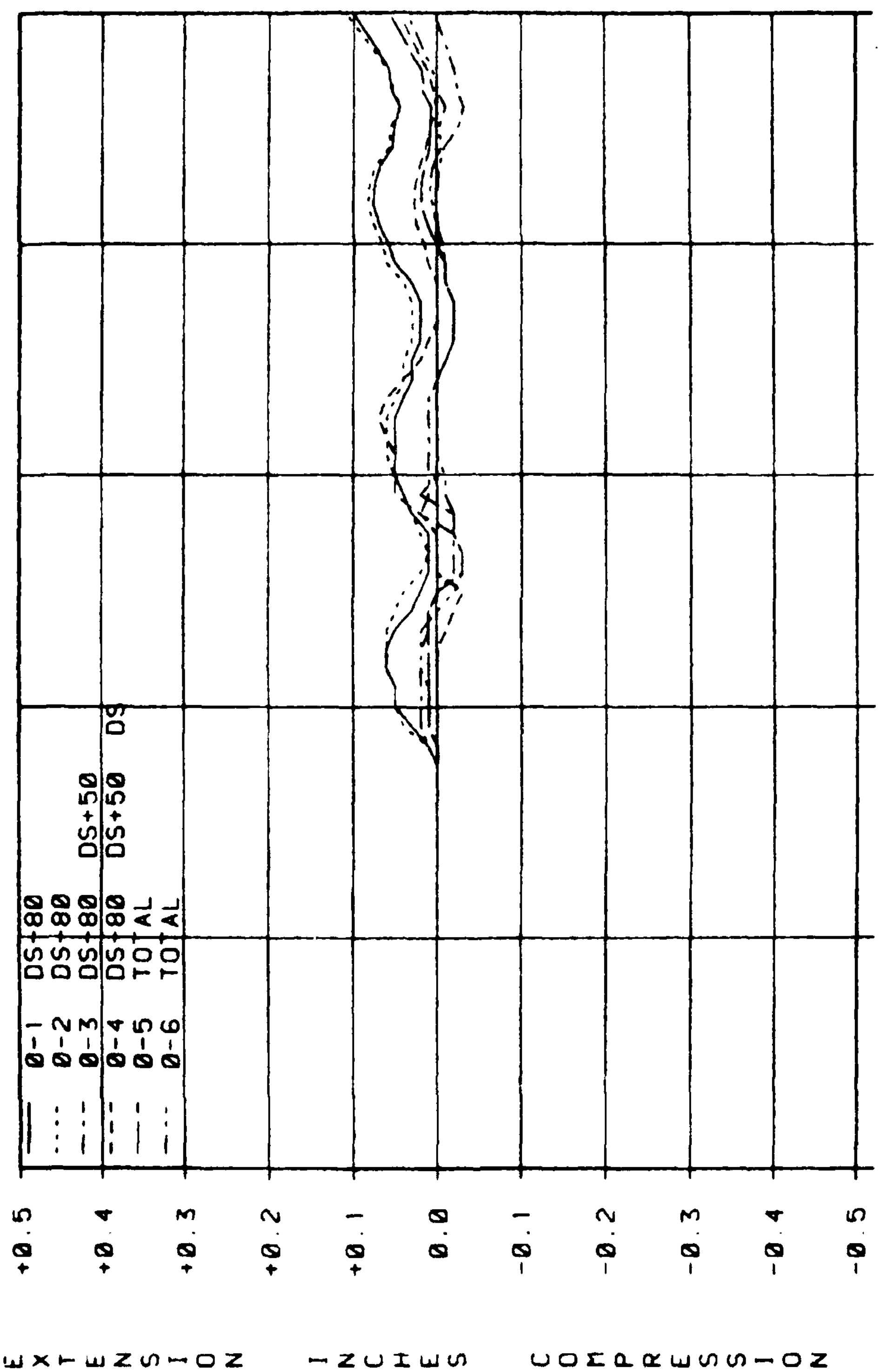
LIBBY LEFT BANK L12 (FLOATING HEAD)



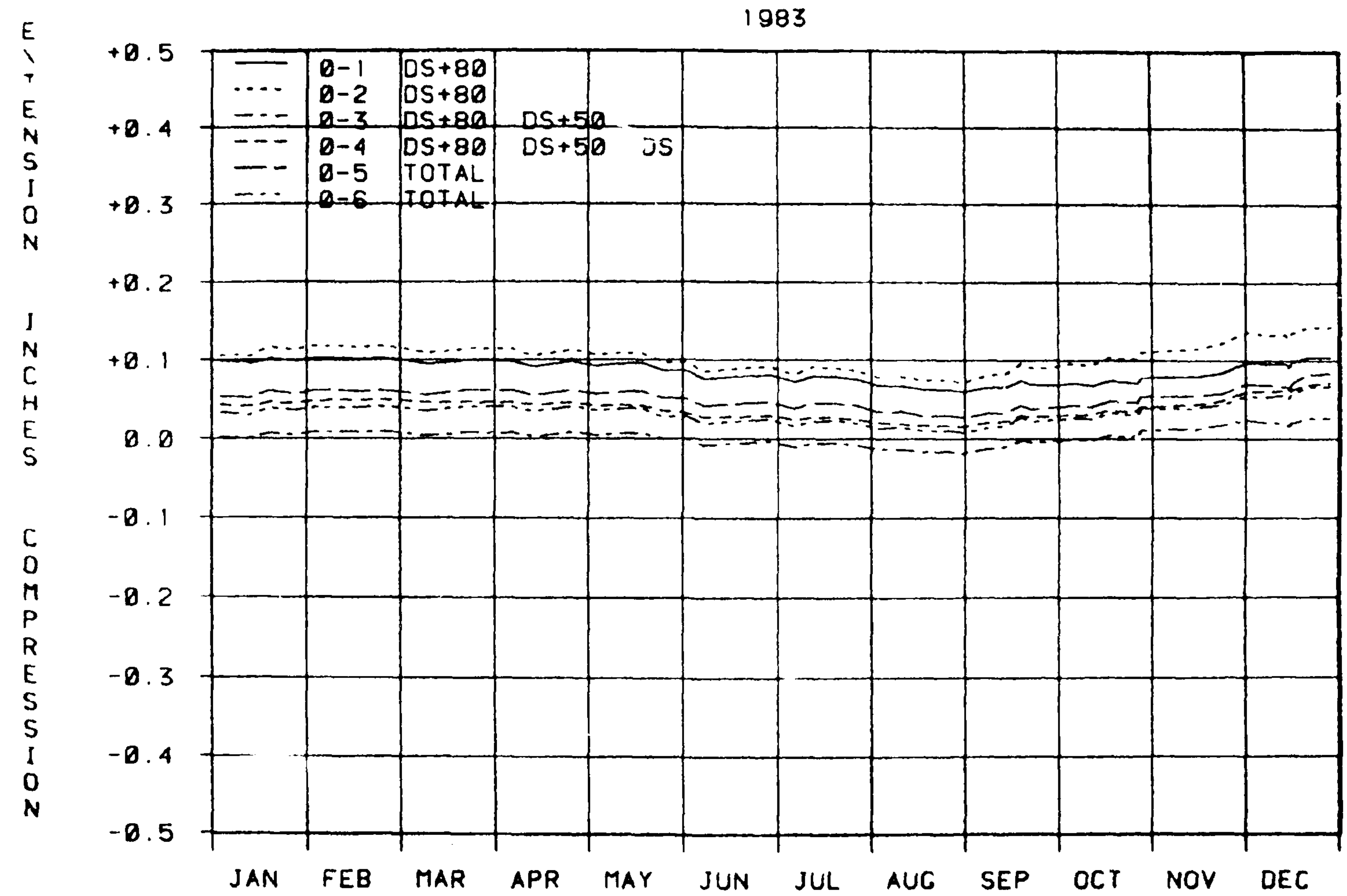
LIBBY LEFT BANK L12 (FLOATING HEAD)



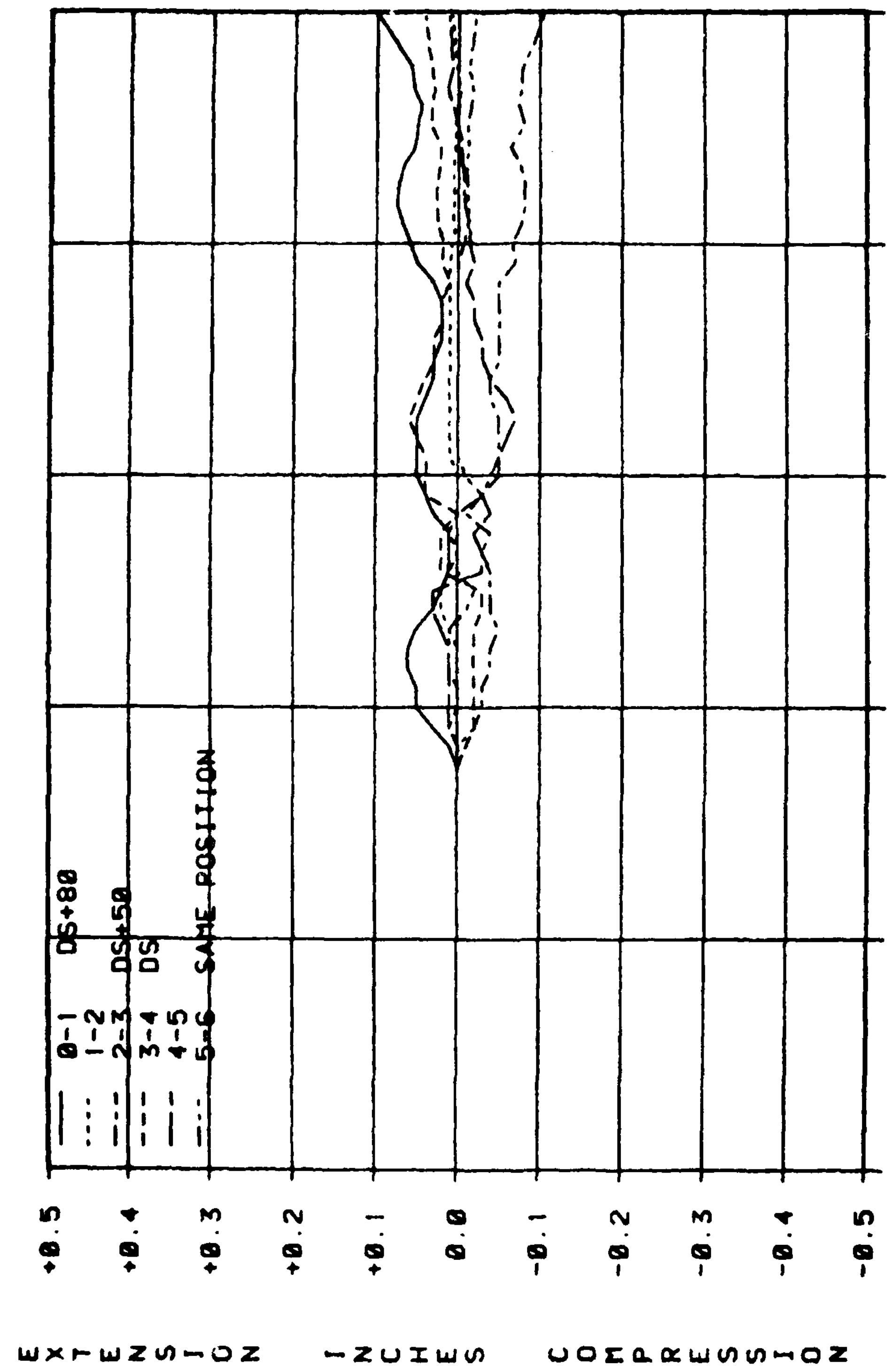
LIBBY LEFT BANK L12 (FLOATING HEAD)
0-4 DS+80 N-S DS
1-4 DS+80 N-S DS
2-4 N-S DS
3-4 DS
1978
1979
1980
1981
1982
+0.5
+0.4
+0.3
+0.2
+0.1
0.0
-0.1
-0.2
-0.3
-0.4
-0.5
EXTENSION INCHES COMPRESSION



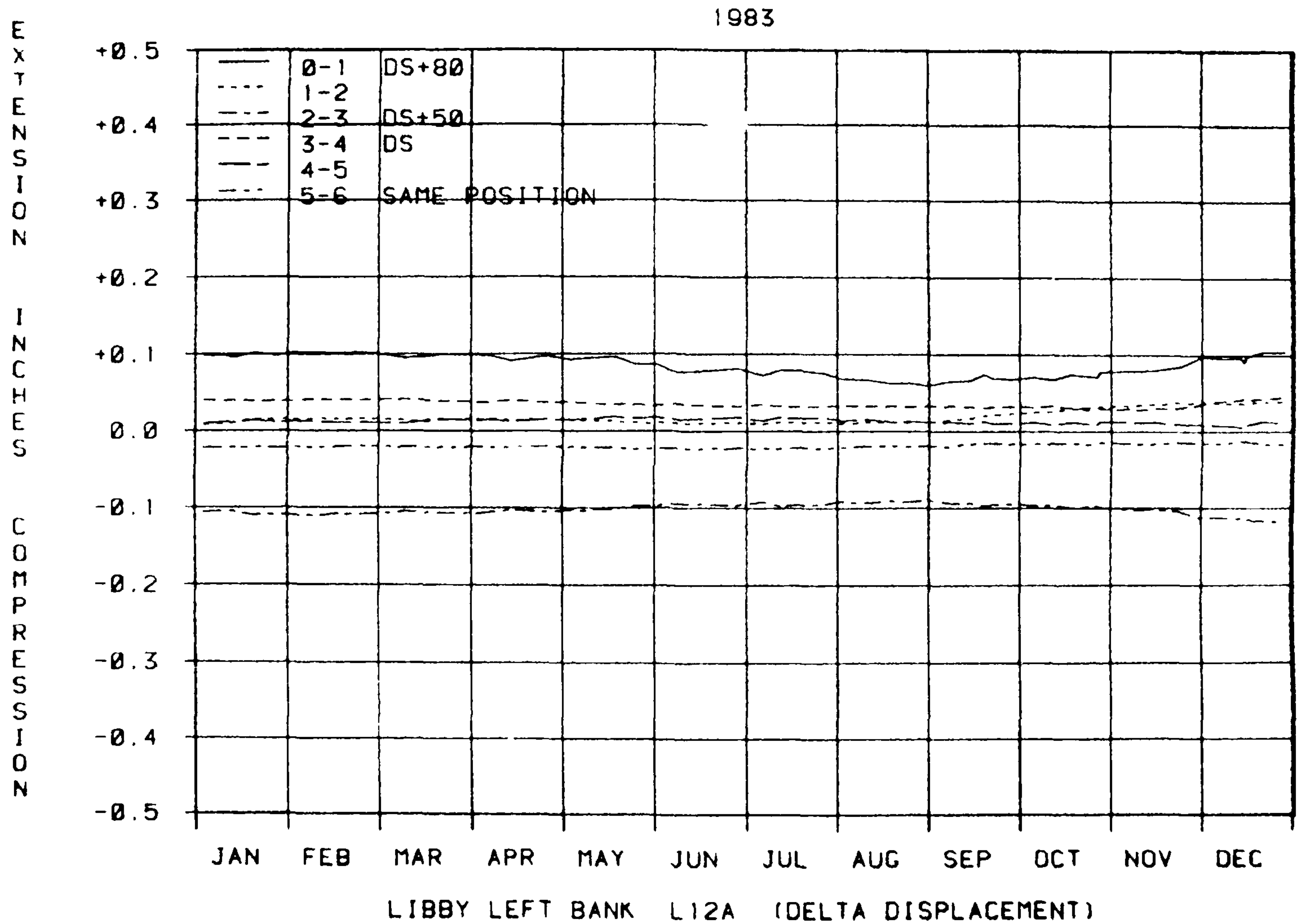
LIBBY LEFT BANK L12A (DISPLACEMENT)



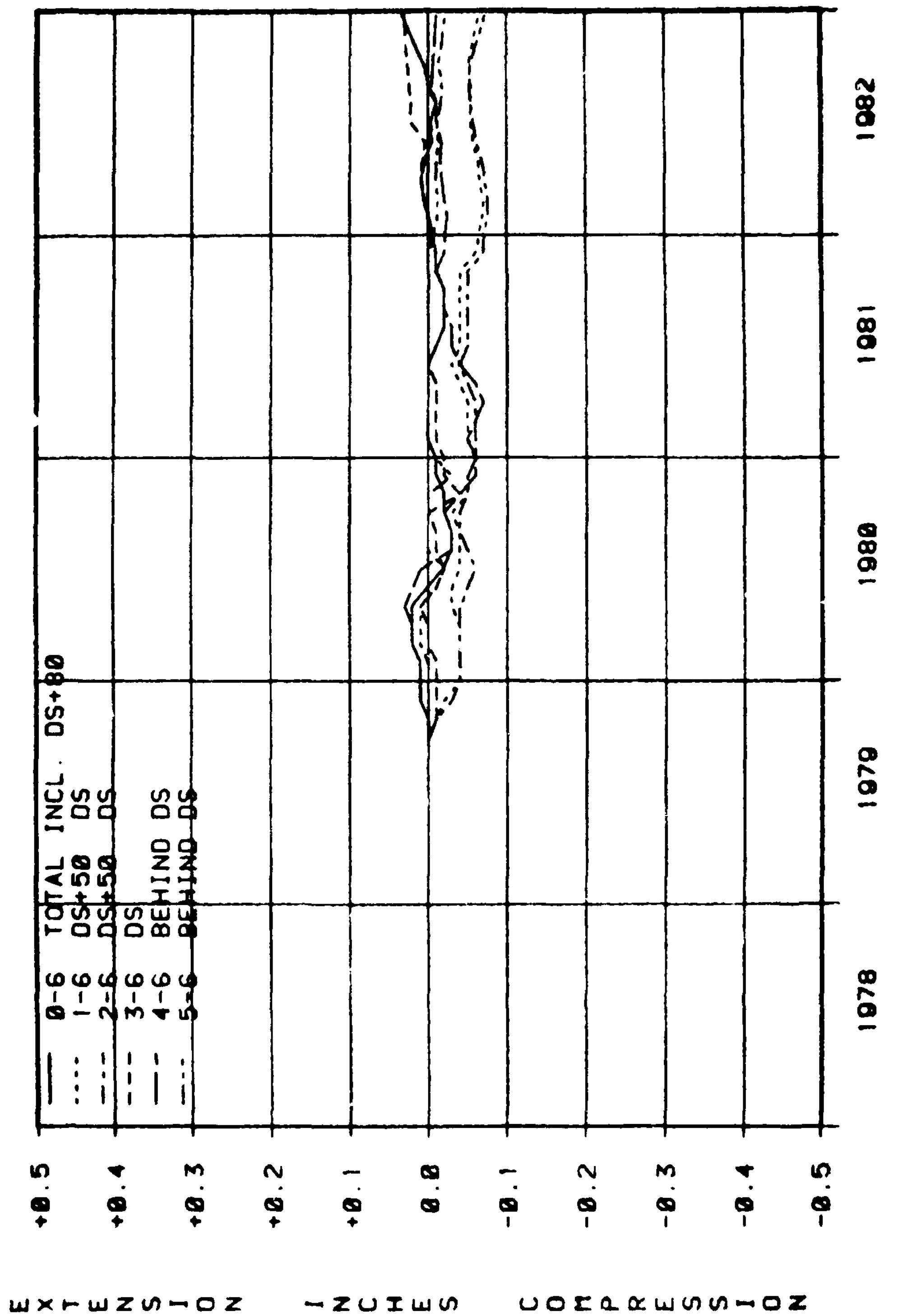
LIBBY LEFT BANK L12A (DISPLACEMENT)



LIBBY LEFT BANK L12A (DELTA DISPLACEMENT)



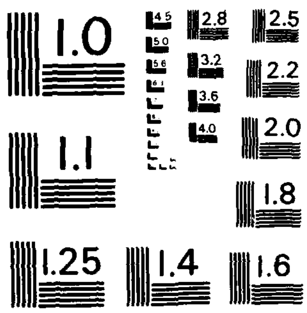
1983
EXTENSION INCHES COMPRESSION
+0.5
+0.4
+0.3
+0.2
+0.1
0.0
-0.1
-0.2
-0.3
-0.4
-0.5
0-1 DS+80
1-2
2-3 DS+50
3-4 DS
4-5
5-6 SAME POSITION
JAN FEB MAR APR MAY JUN JUL AUG SEP OCT NOV DEC
LIBBY LEFT BANK L12A (DELTA DISPLACEMENT)



LIBBY LEFT BANK L12A (FLOATING HEAD)

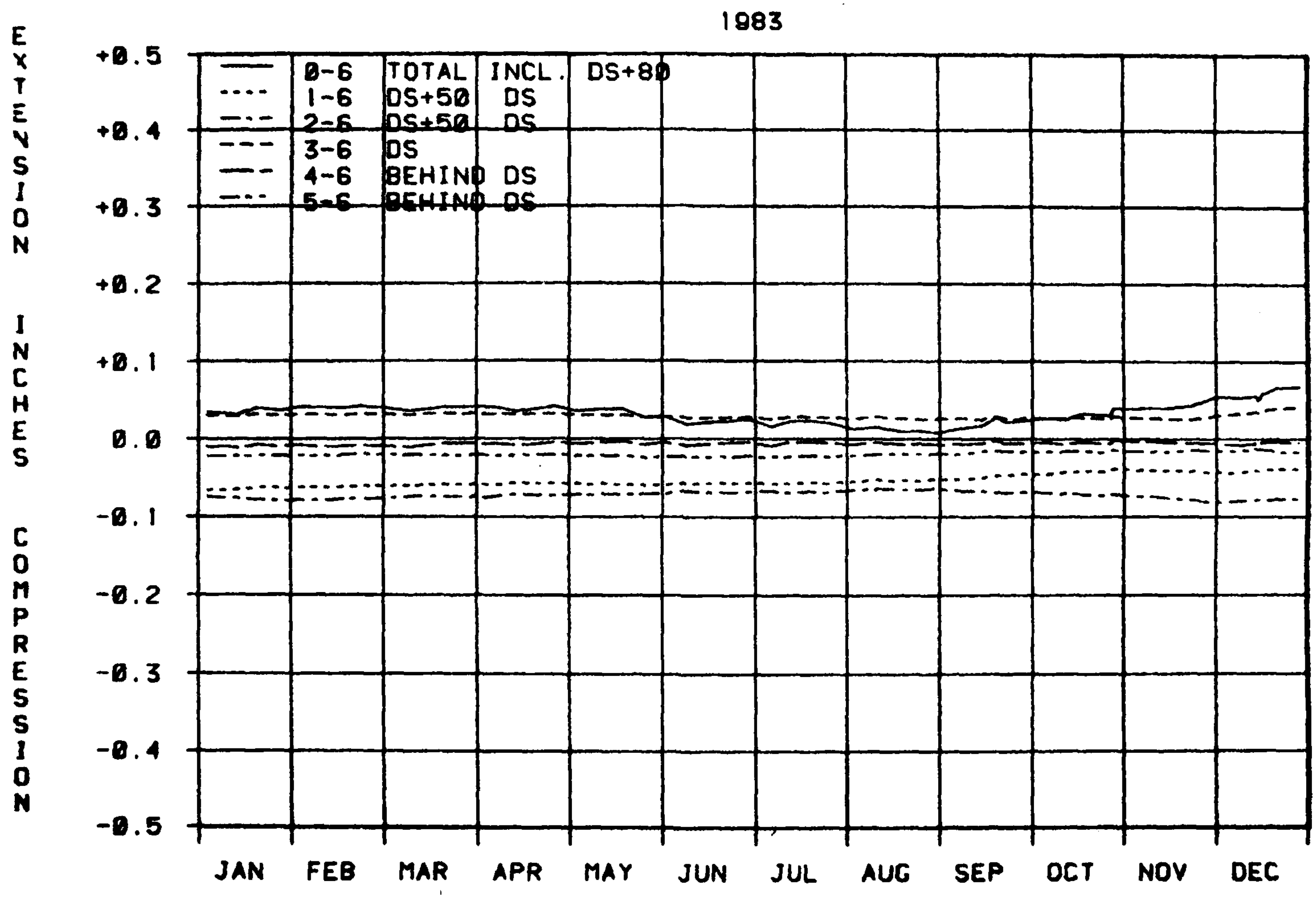
AD-A142 021 LIBBY DAM AND LAKE KOOCANUSA PROJECT MONTANA LEFT BANK SLOPE(U) CORPS OF ENGINEERS SEATTLE WA SEATTLE DISTRICT APR 84 4/6

UNCLASSIFIED F/G 13/2 NL

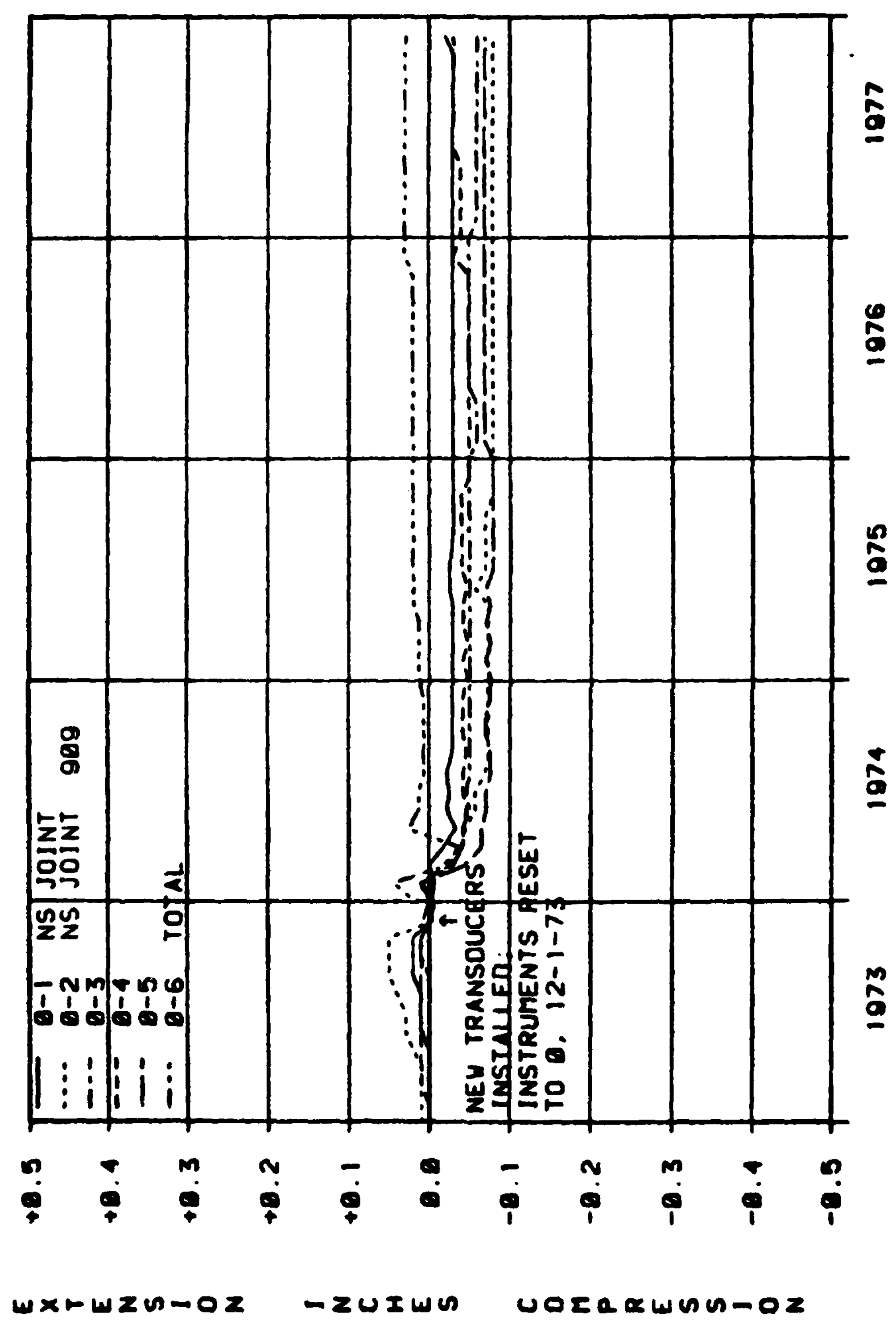


MICROCOPY RESOLUTION TEST CHART

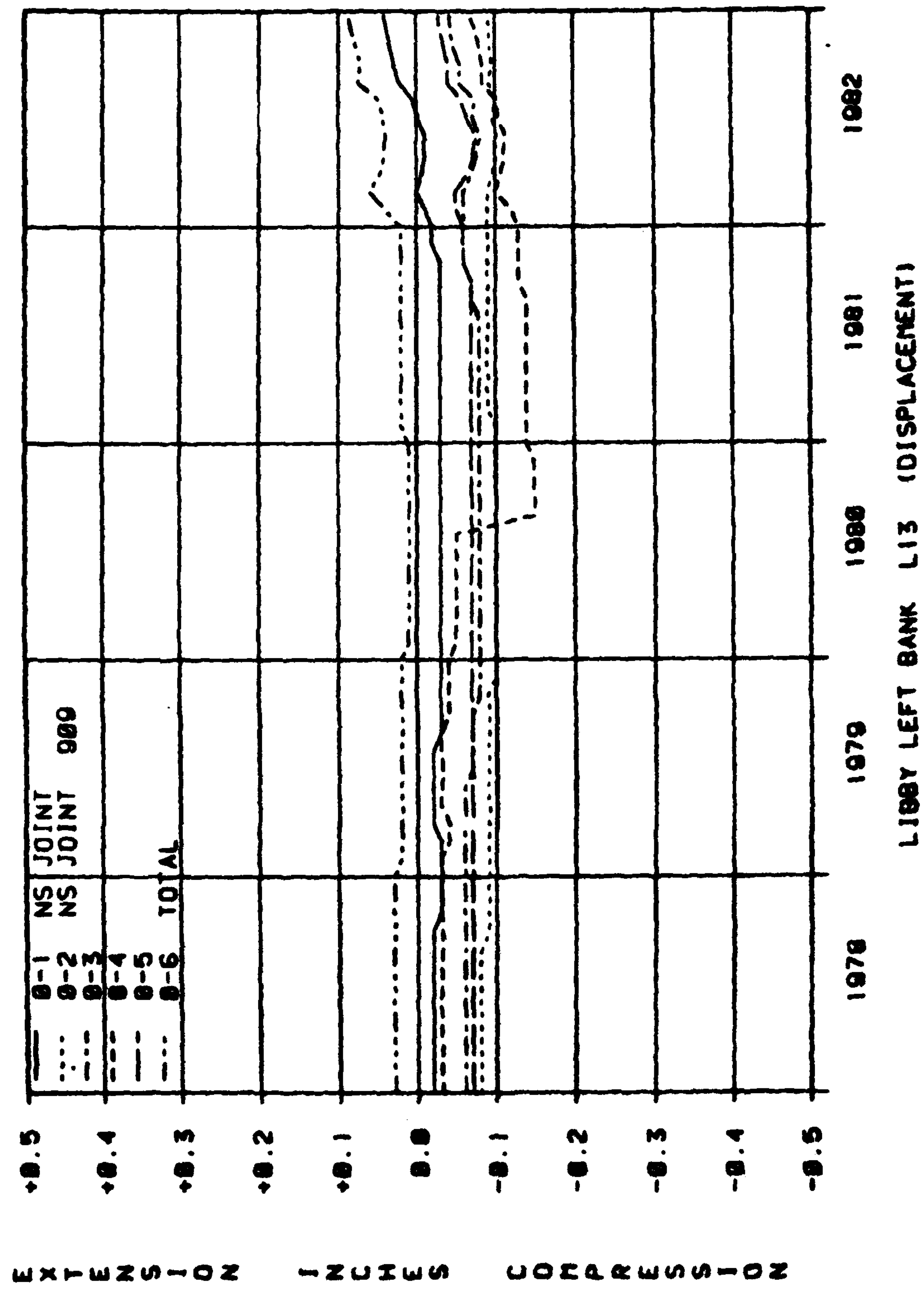
NATIONAL BUREAU OF STANDARDS-1963-A



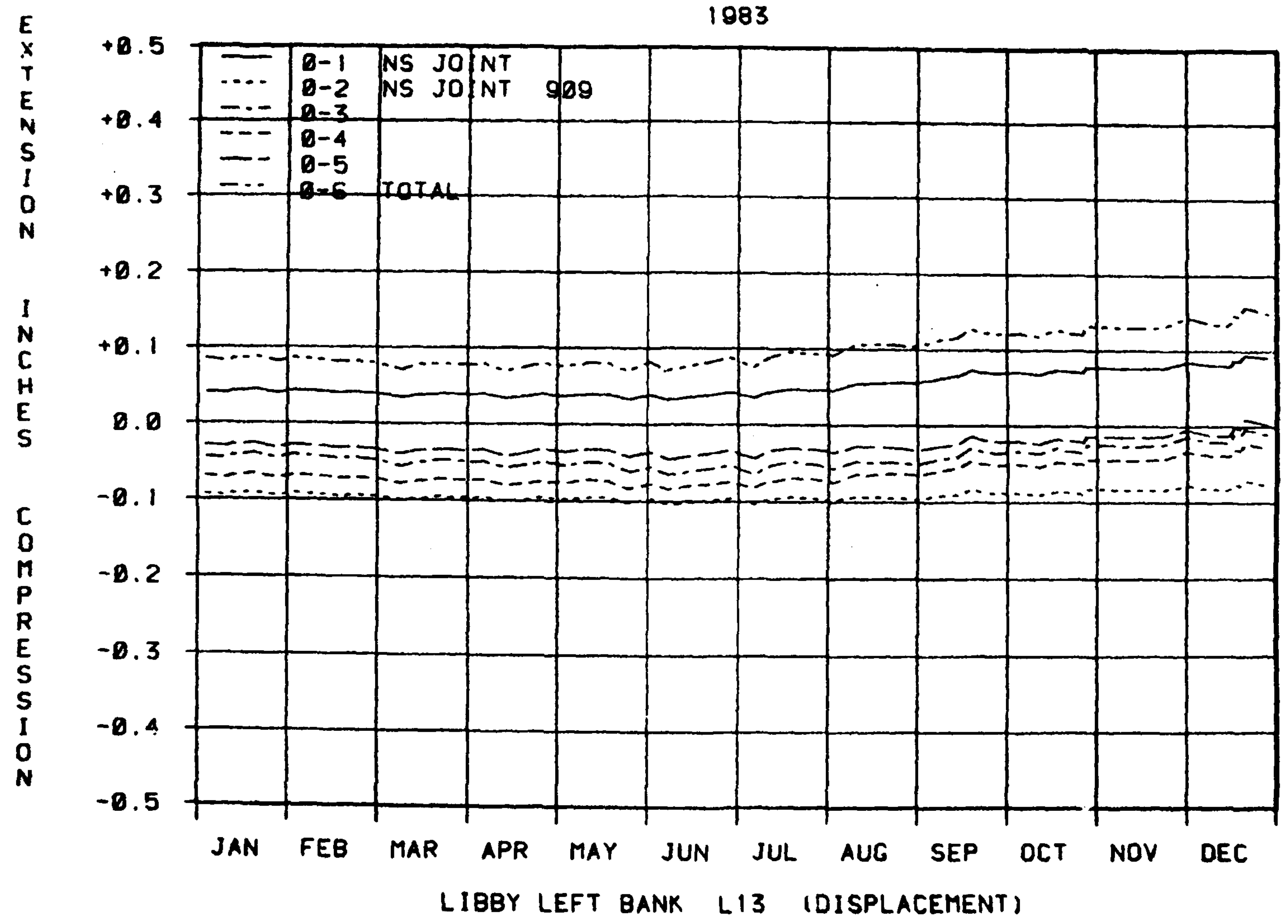
LIBBY LEFT BANK L12A (FLOATING HEAD)

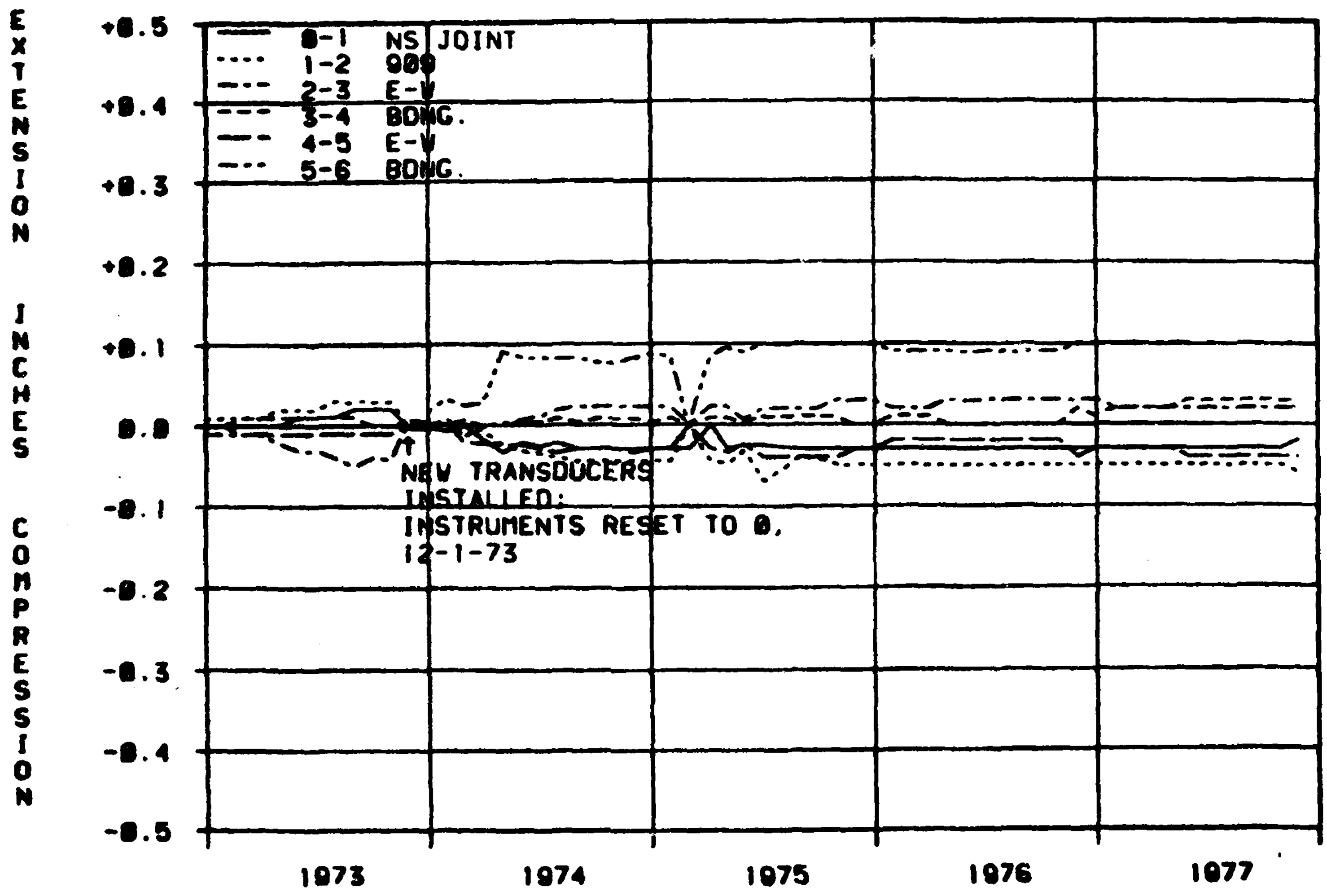


LIBBY LEFT BANK L13 (DISPLACEMENT)

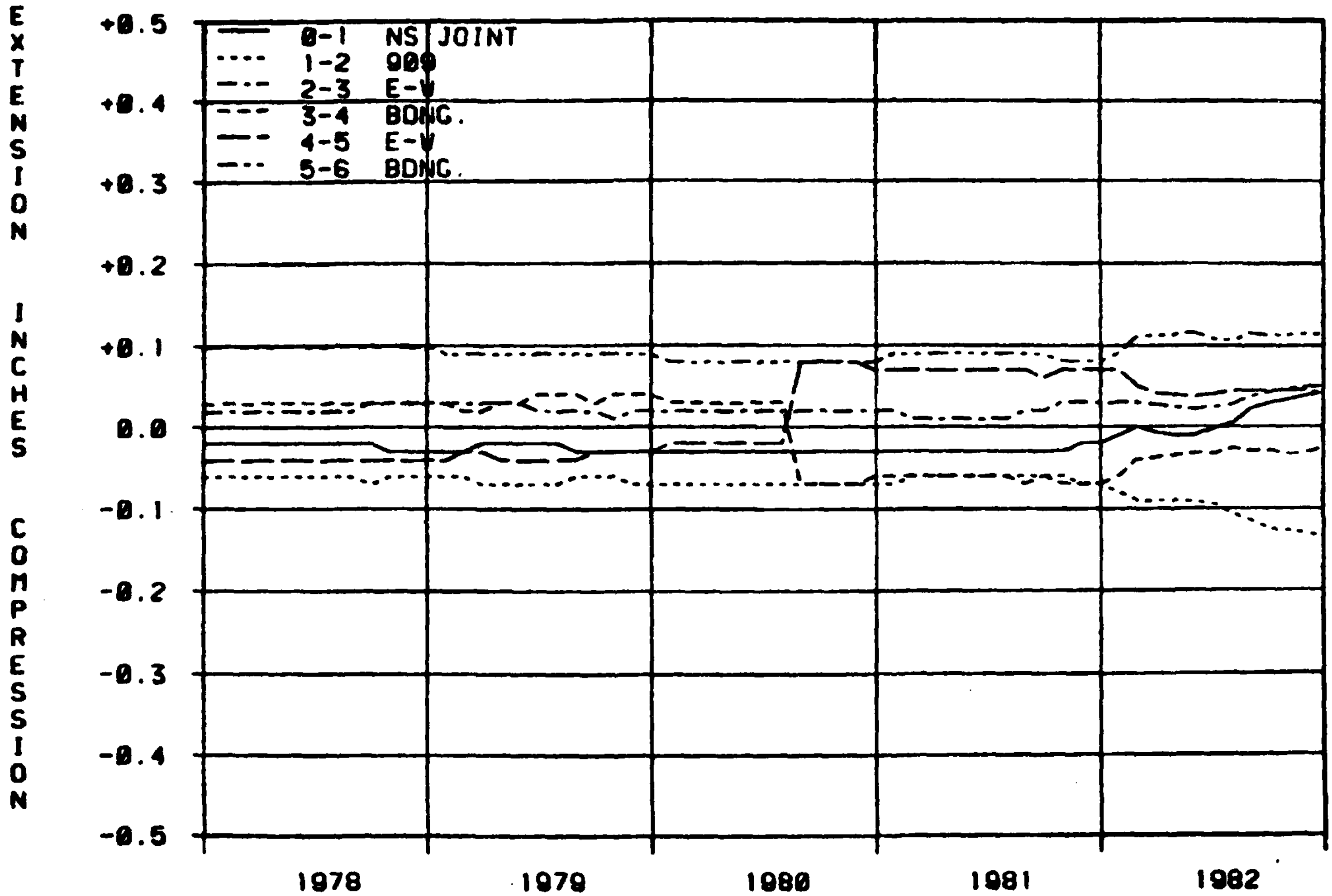


0-1 NS JOINT 909
0-2 NS JOINT
0-3
0-4
0-5
0-6 TOTAL
+0.5
+0.4
+0.3
+0.2
+0.1
0.0
-0.1
-0.2
-0.3
-0.4
-0.5
EXTENSION INCHES COMPRESSION
1978
1979
1980
1981
1982
LIBBY LEFT BANK L13 (DISPLACEMENT)

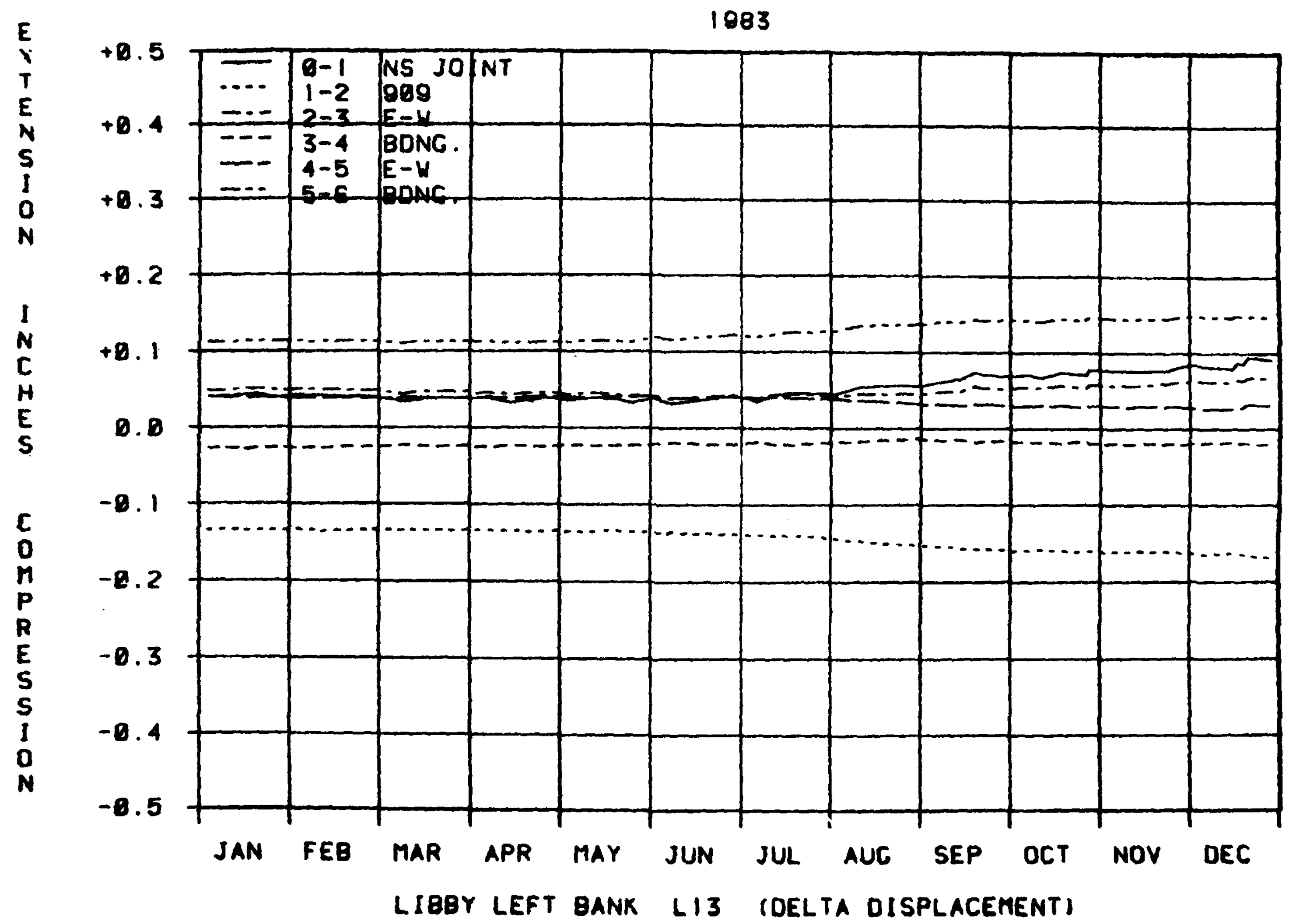

1983
0-1 NS JOINT
0-2 NS JOINT 909
0-3
0-4
0-5
0-6 TOTAL
EXTENSION INCHES COMPRESSION
+0.5
+0.4
+0.3
+0.2
+0.1
0.0
-0.1
-0.2
-0.3
-0.4
-0.5
JAN FEB MAR APR MAY JUN JUL AUG SEP OCT NOV DEC
LIBBY LEFT BANK L13 (DISPLACEMENT)

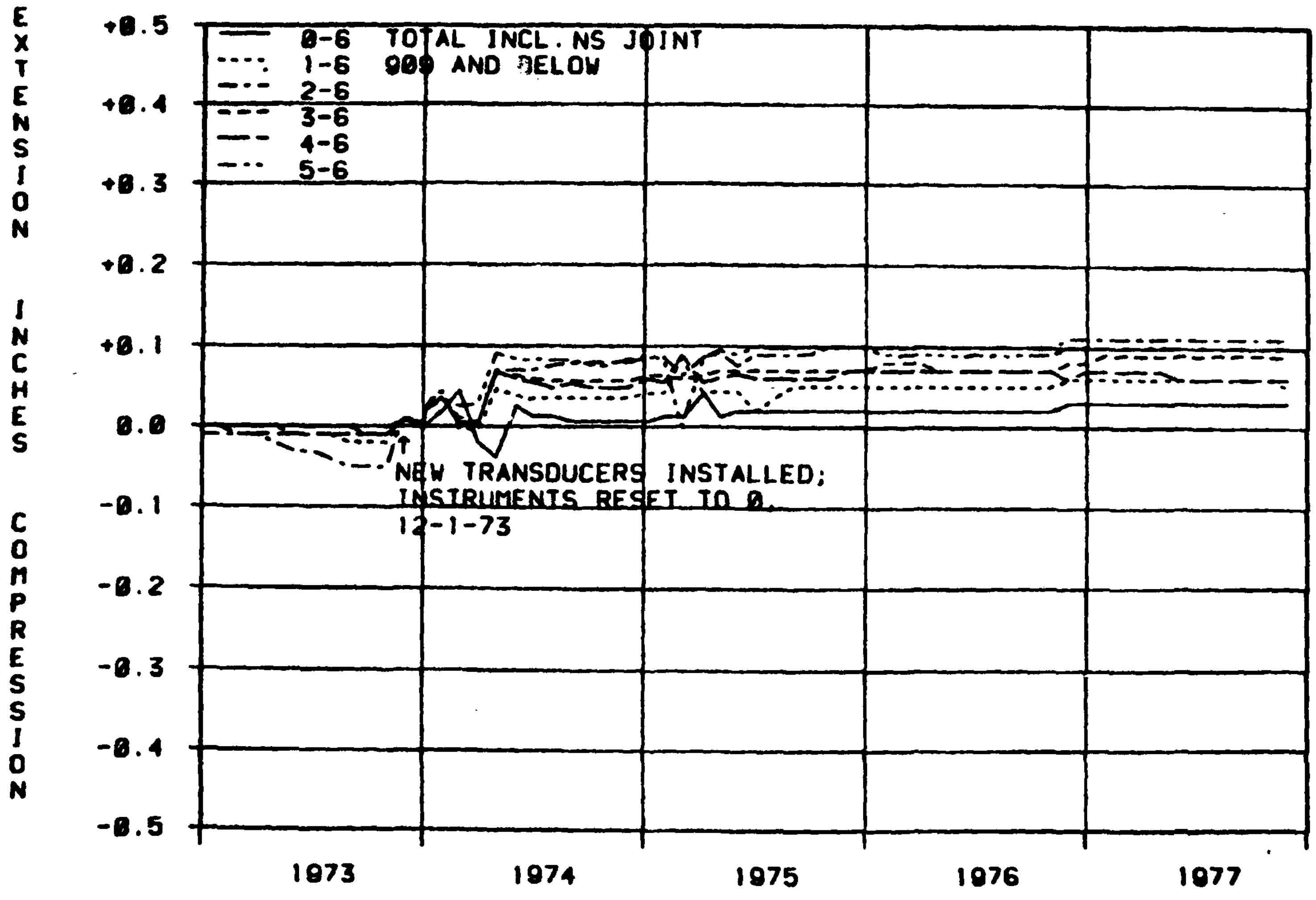


LIBBY LEFT BANK L13 (DELTA DISPLACEMENT)

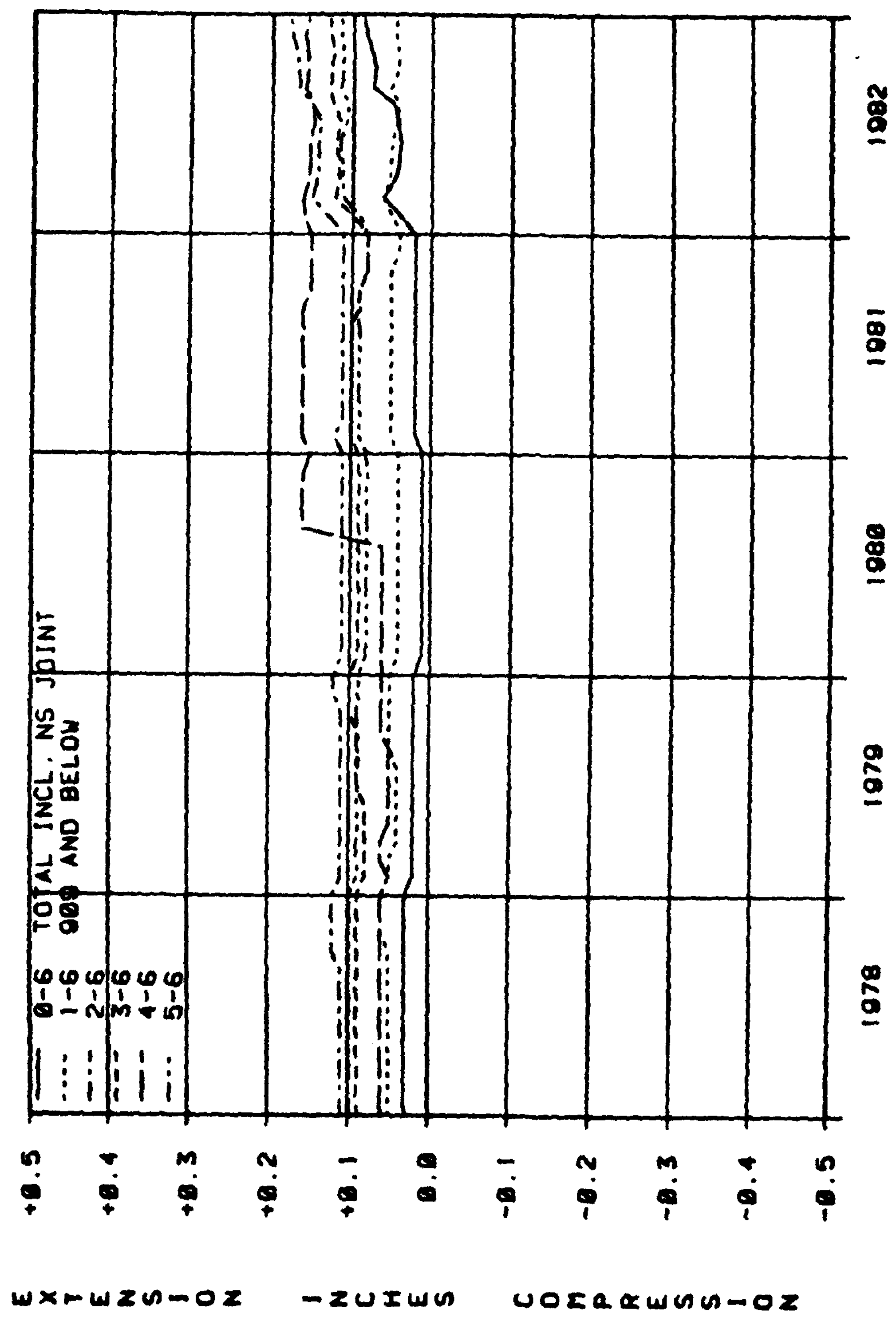


LIBBY LEFT BANK L13 (DELTA DISPLACEMENT)

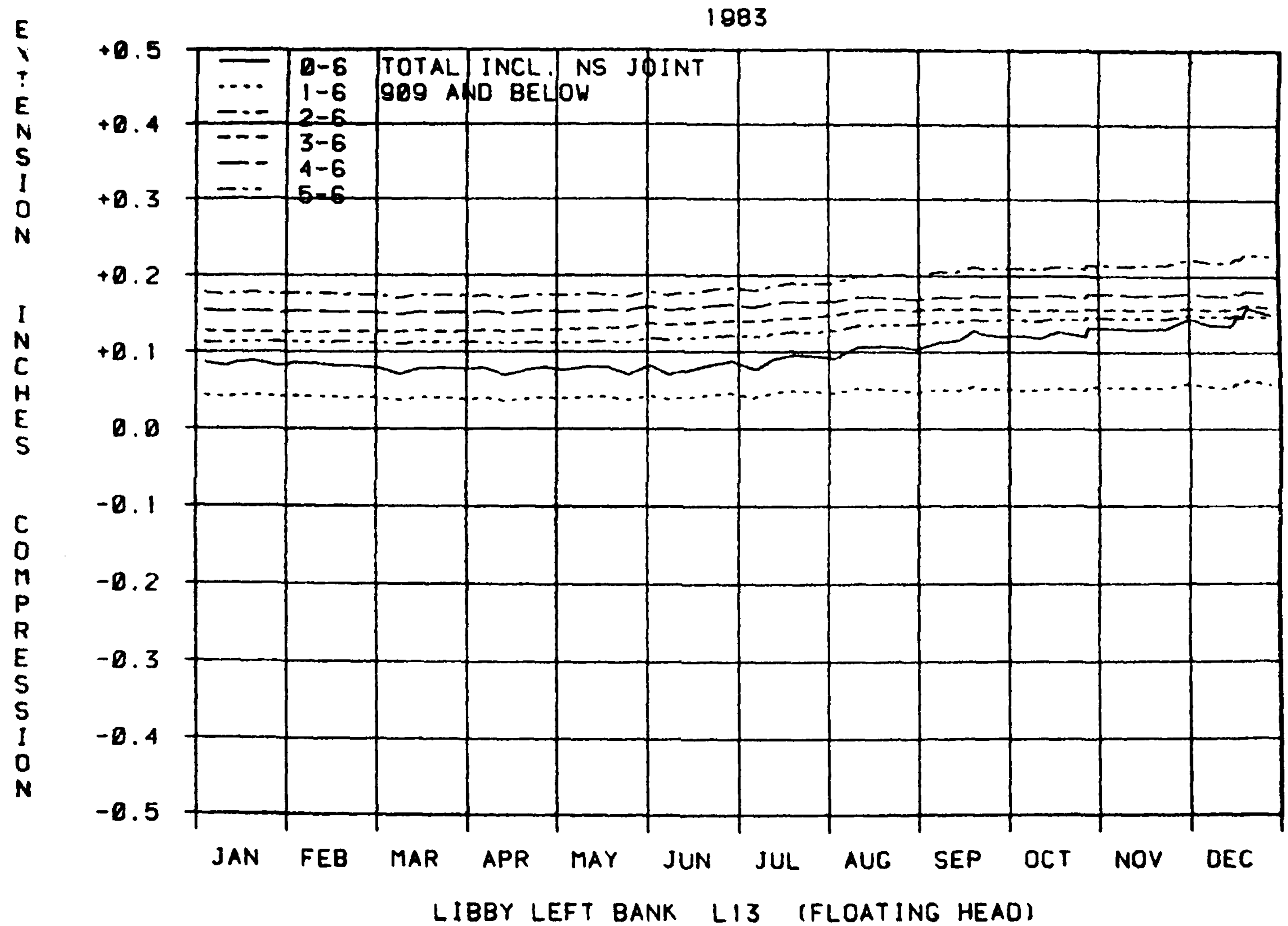

1983
EXTENSION INCHES COMPRESSION
+0.5
+0.4
+0.3
+0.2
+0.1
0.0
-0.1
-0.2
-0.3
-0.4
-0.5
0-1 NS JOINT
1-2 909
2-3 E-W
3-4 BDNG.
4-5 E-W
5-6 BDNG.
JAN FEB MAR APR MAY JUN JUL AUG SEP OCT NOV DEC
LIBBY LEFT BANK L13 (DELTA DISPLACEMENT)

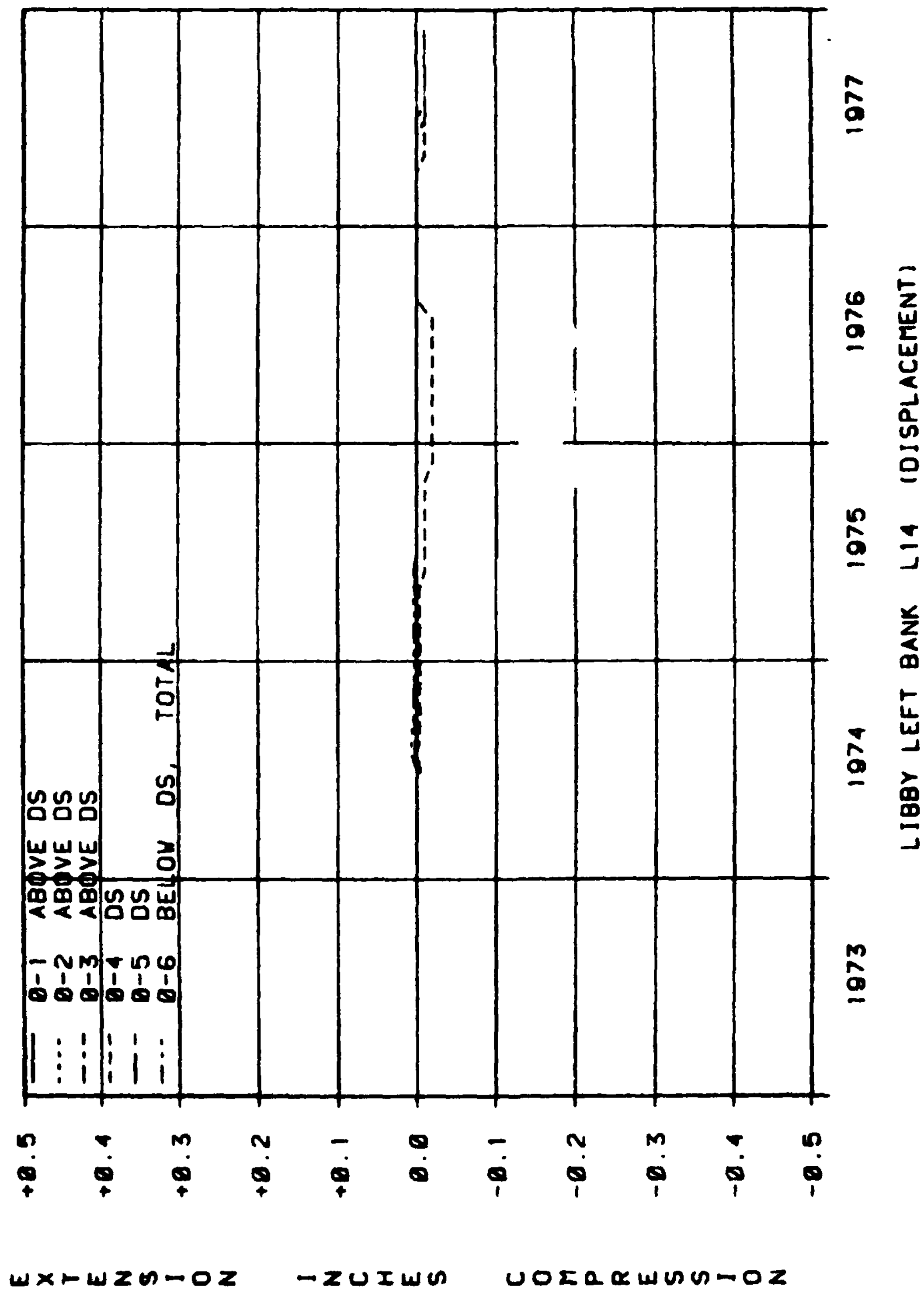


LIBBY LEFT BANK L13 (FLOATING HEAD)

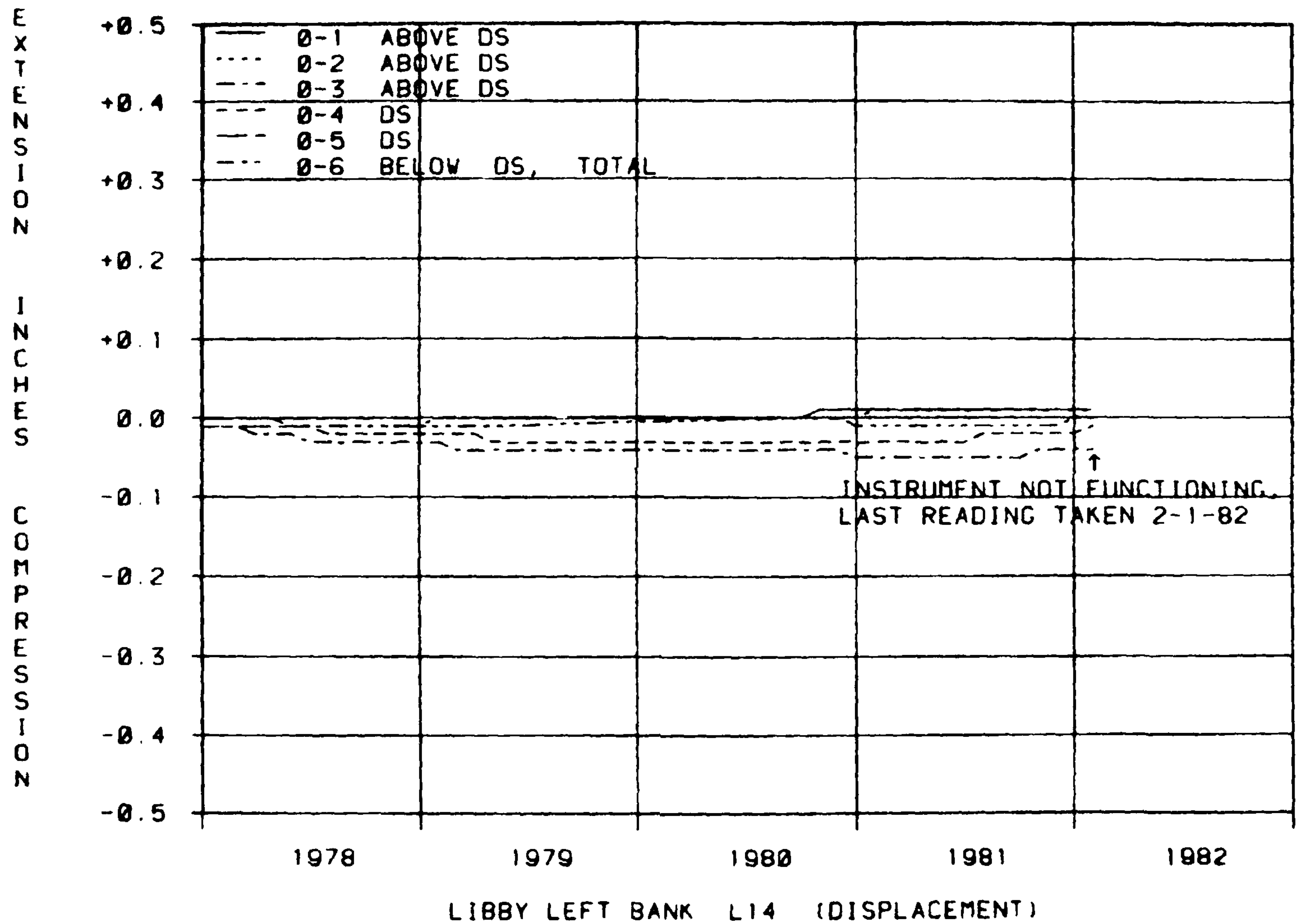


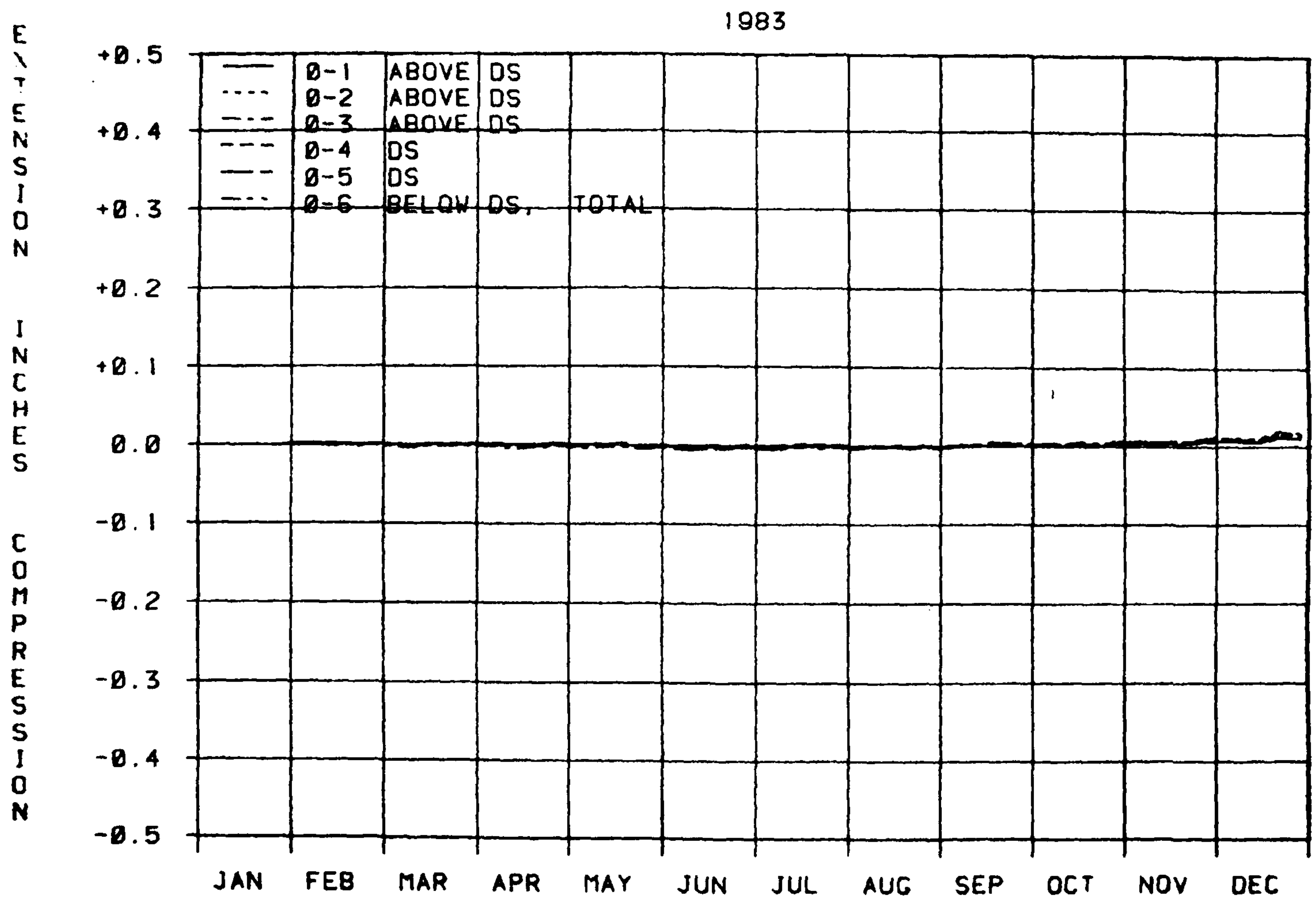
LIBBY LEFT BANK L13 (FLOATING HEAD)


1983
EXTENSION INCHES COMPRESSION
+0.5
+0.4
+0.3
+0.2
+0.1
0.0
-0.1
-0.2
-0.3
-0.4
-0.5
0-6 TOTAL INCL. NS JOINT
1-6 909 AND BELOW
2-6
3-6
4-6
5-6
JAN FEB MAR APR MAY JUN JUL AUG SEP OCT NOV DEC
LIBBY LEFT BANK L13 (FLOATING HEAD)

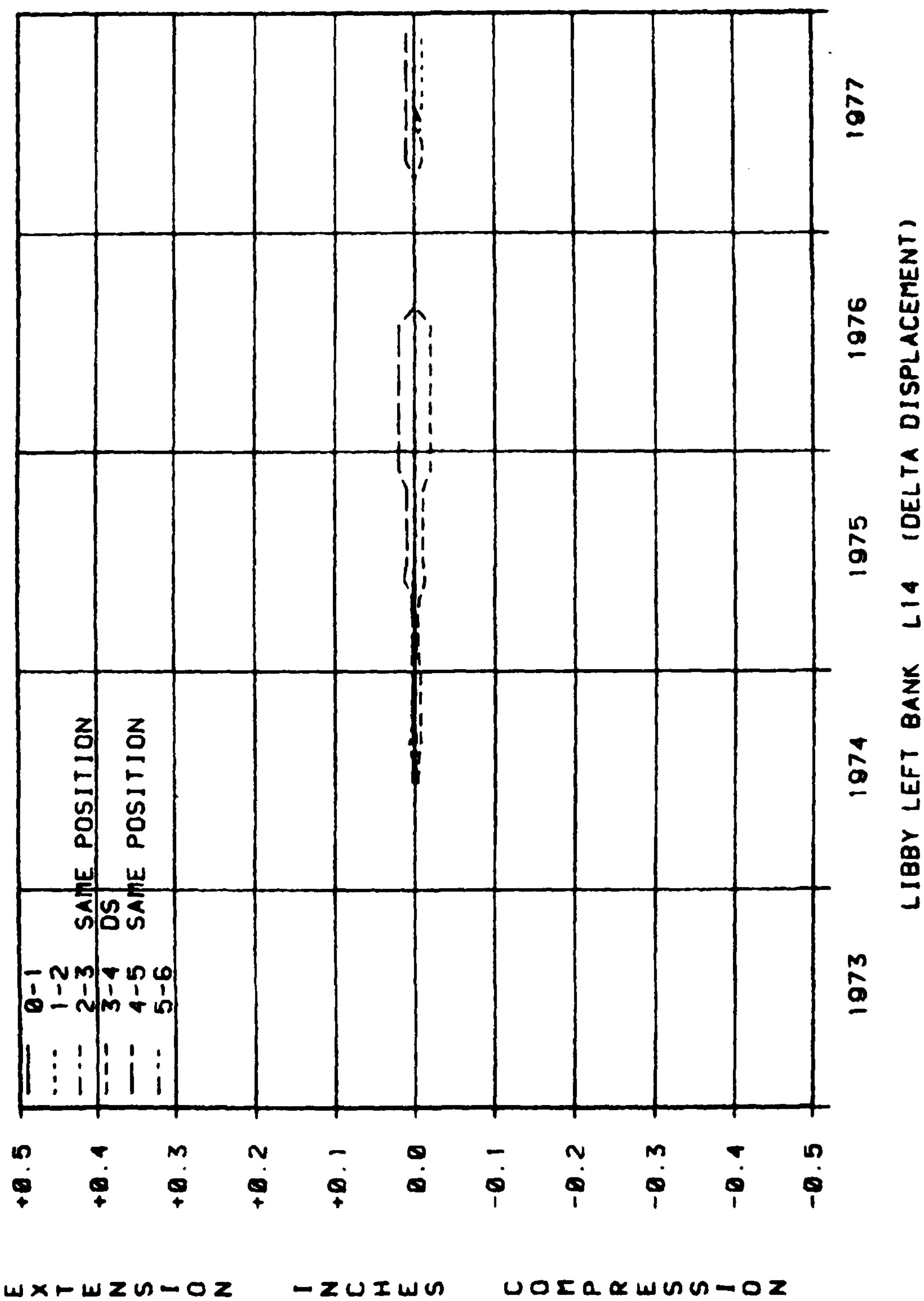


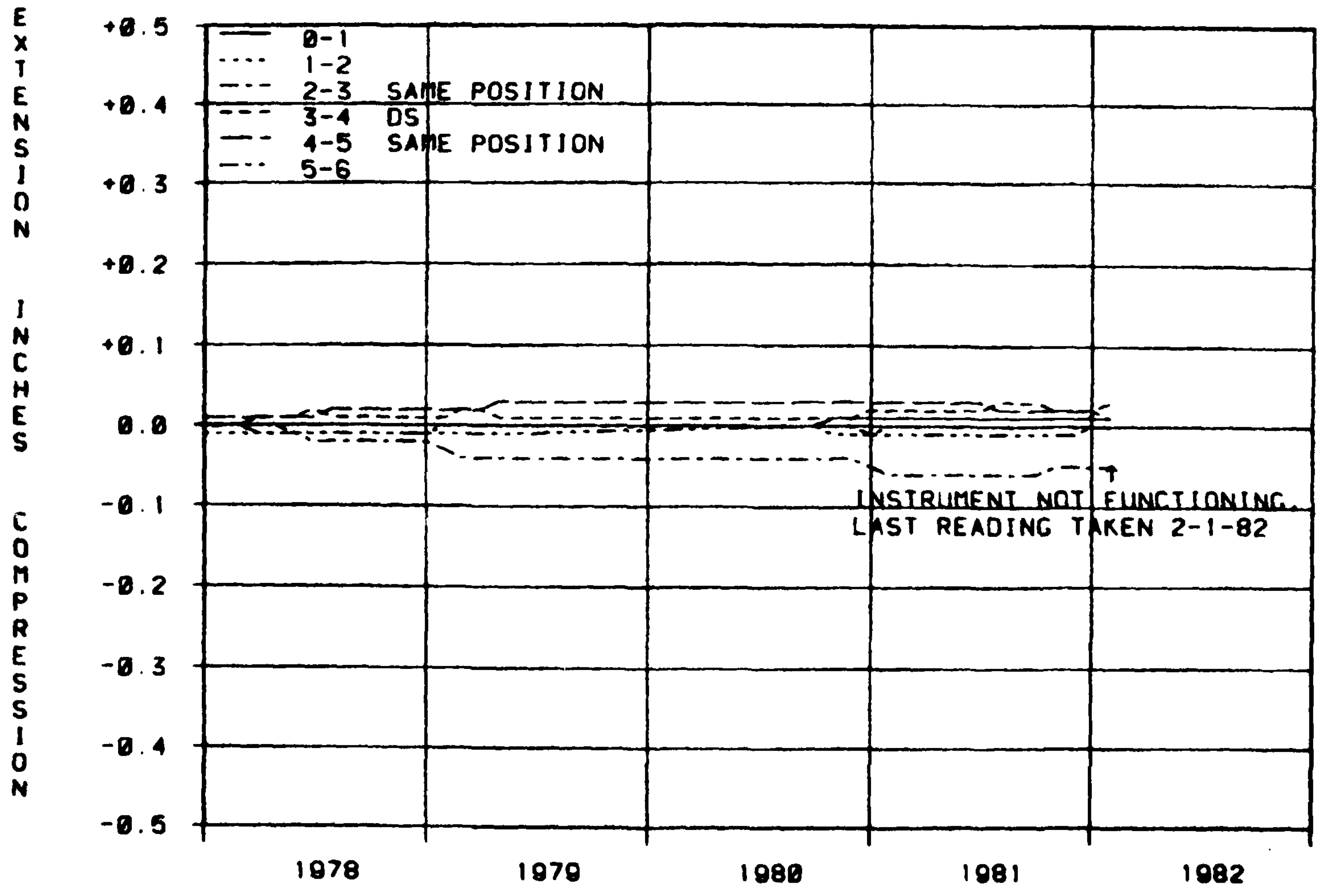
Ø-1 ABOVE DS
Ø-2 ABOVE DS
Ø-3 ABOVE DS
Ø-4 DS
Ø-5 DS
Ø-6 BELOW DS, TOTAL
+Ø.5
+Ø.4
+Ø.3
+Ø.2
+Ø.1
Ø.Ø
-Ø.1
-Ø.2
-Ø.3
-Ø.4
-Ø.5
EXTENSION INCHES COMPRESSION
1973
1974
1975
1976
1977
LIBBY LEFT BANK L14 (DISPLACEMENT)


EXTENSION INCHES COMPRESSION
+0.5
+0.4
+0.3
+0.2
+0.1
0.0
-0.1
-0.2
-0.3
-0.4
-0.5
0-1 ABOVE DS
0-2 ABOVE DS
0-3 ABOVE DS
0-4 DS
0-5 DS
0-6 BELOW DS, TOTAL
INSTRUMENT NOT FUNCTIONING.
LAST READING TAKEN 2-1-82
1978
1979
1980
1981
1982
LIBBY LEFT BANK L14 (DISPLACEMENT)

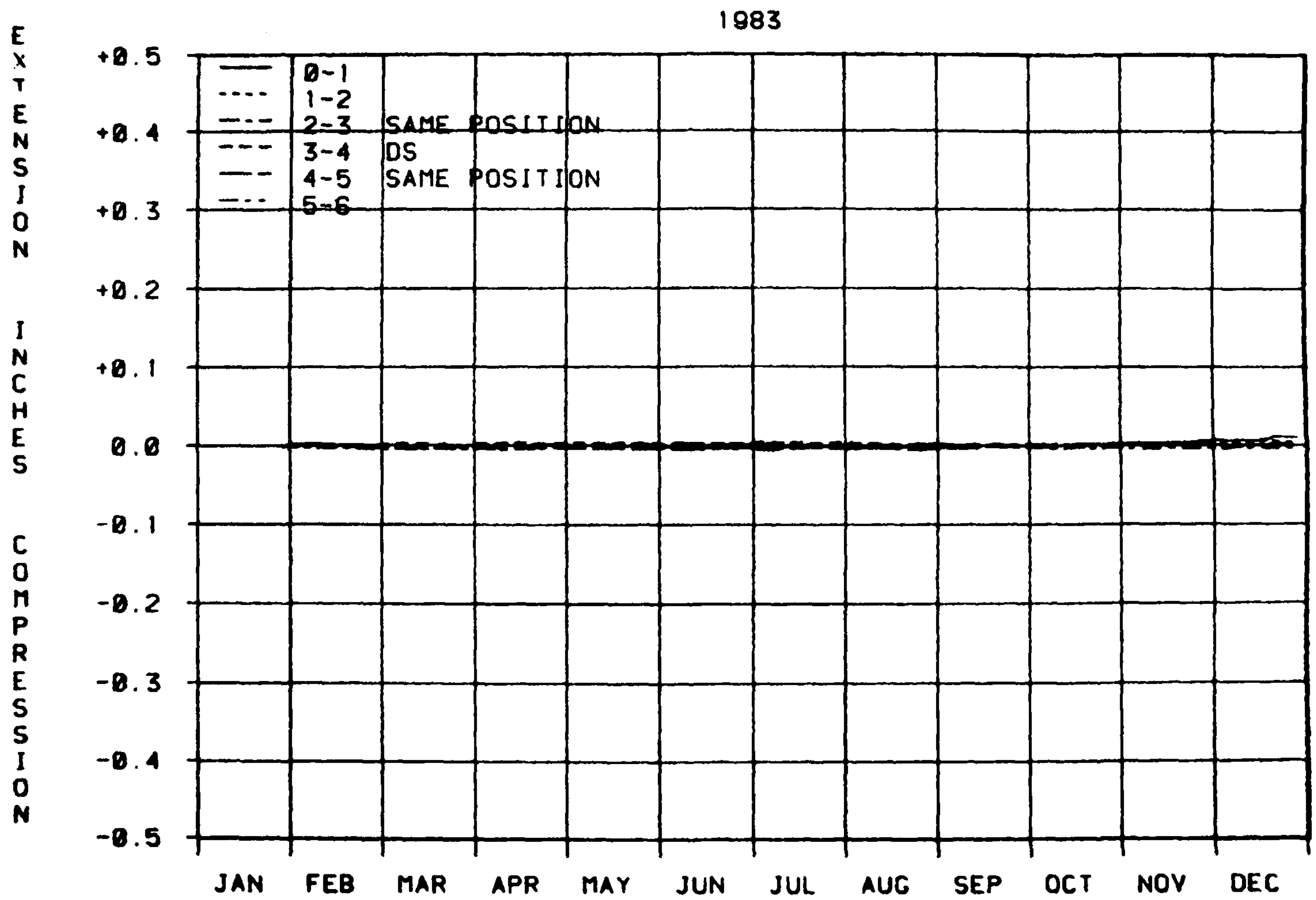


LIBBY LEFT BANK L14 (DISPLACEMENT)

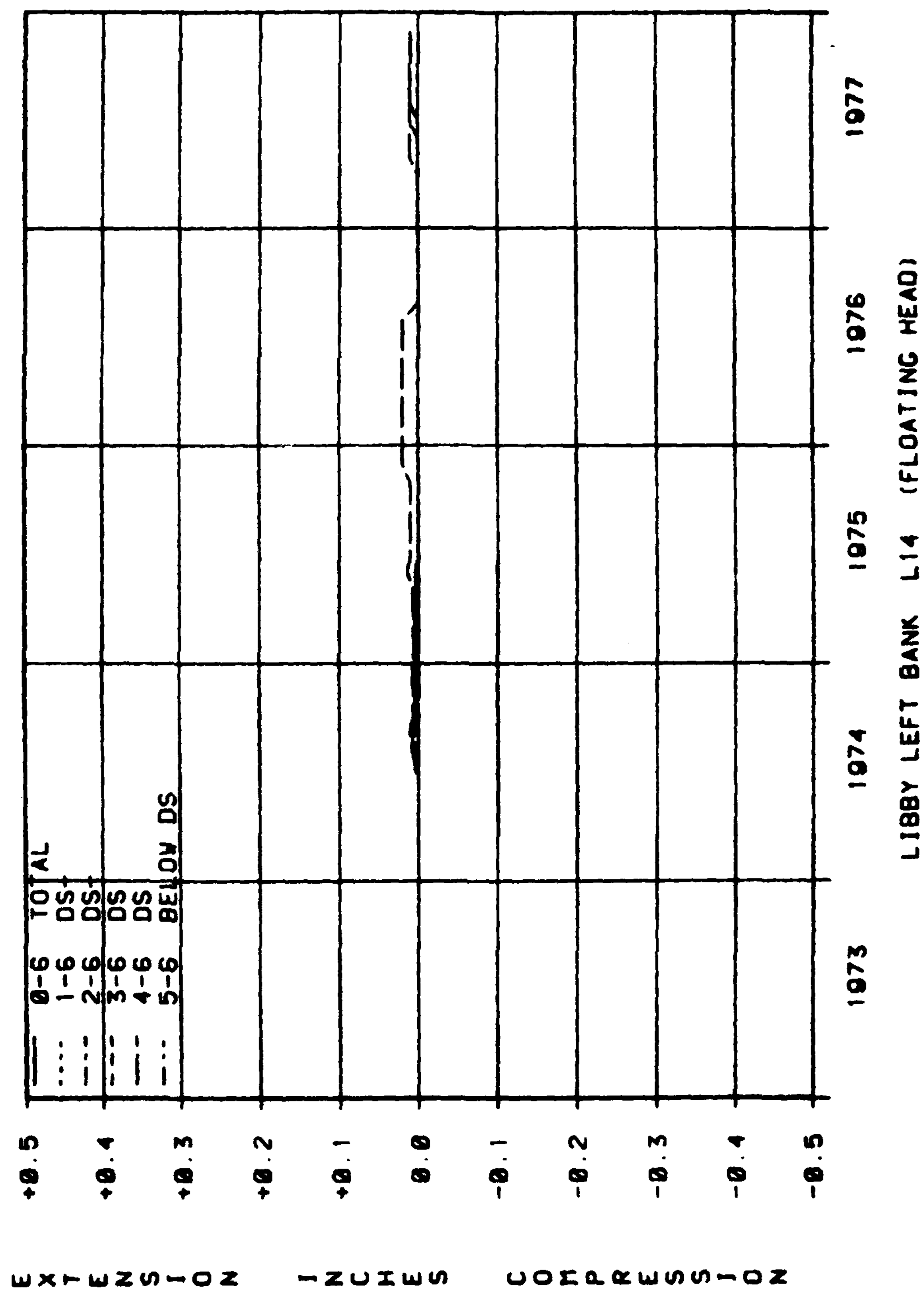

LIBBY LEFT BANK L14 (DELTA DISPLACEMENT)
1973
1974
1975
1976
1977
0-1
1-2
2-3 SAME POSITION
3-4 DS
4-5 SAME POSITION
5-6
+0.5
+0.4
+0.3
+0.2
+0.1
0.0
-0.1
-0.2
-0.3
-0.4
-0.5
EXTENSION INCHES COMPRESSION



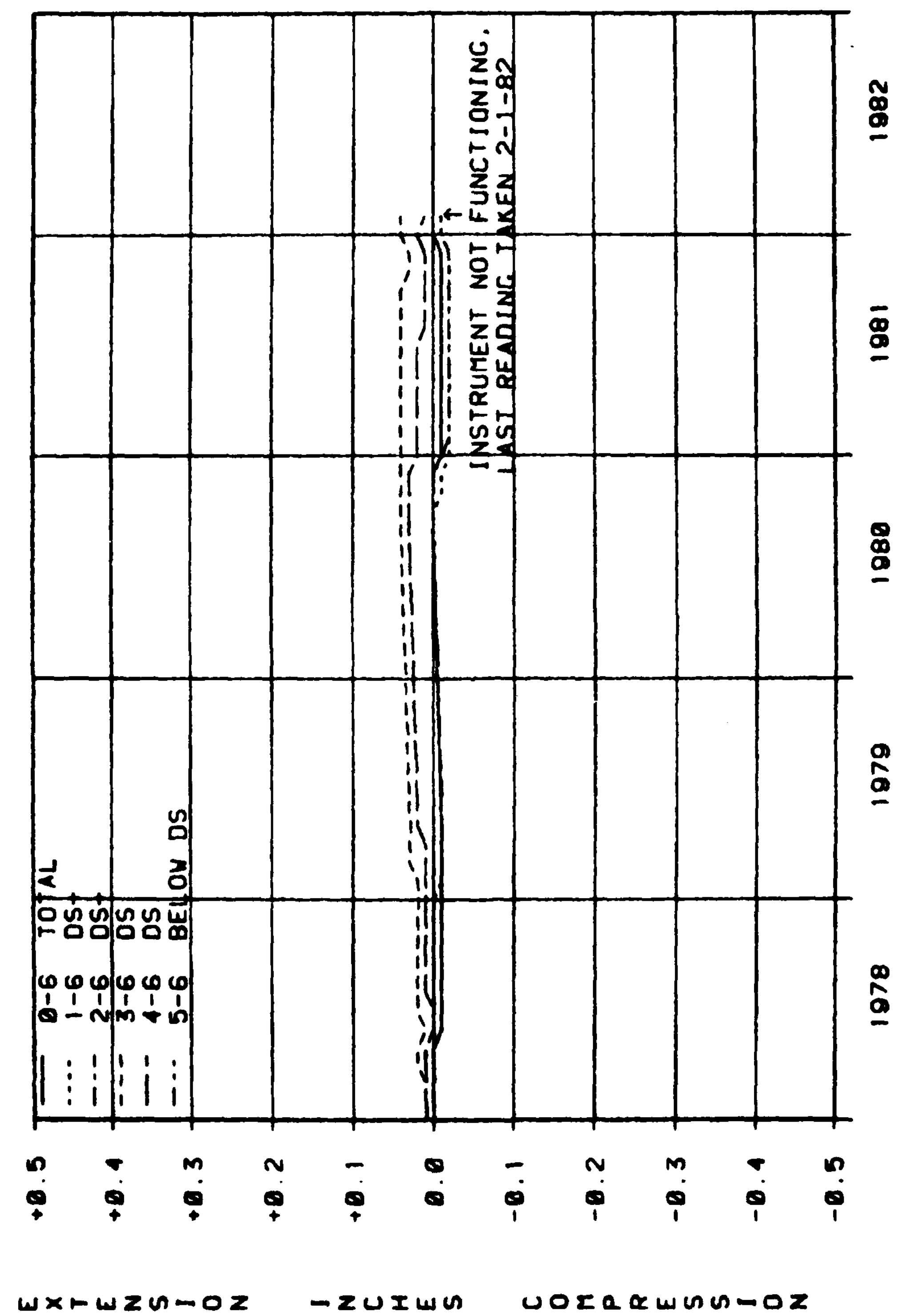
LIBBY LEFT BANK L14 (DELTA DISPLACEMENT)



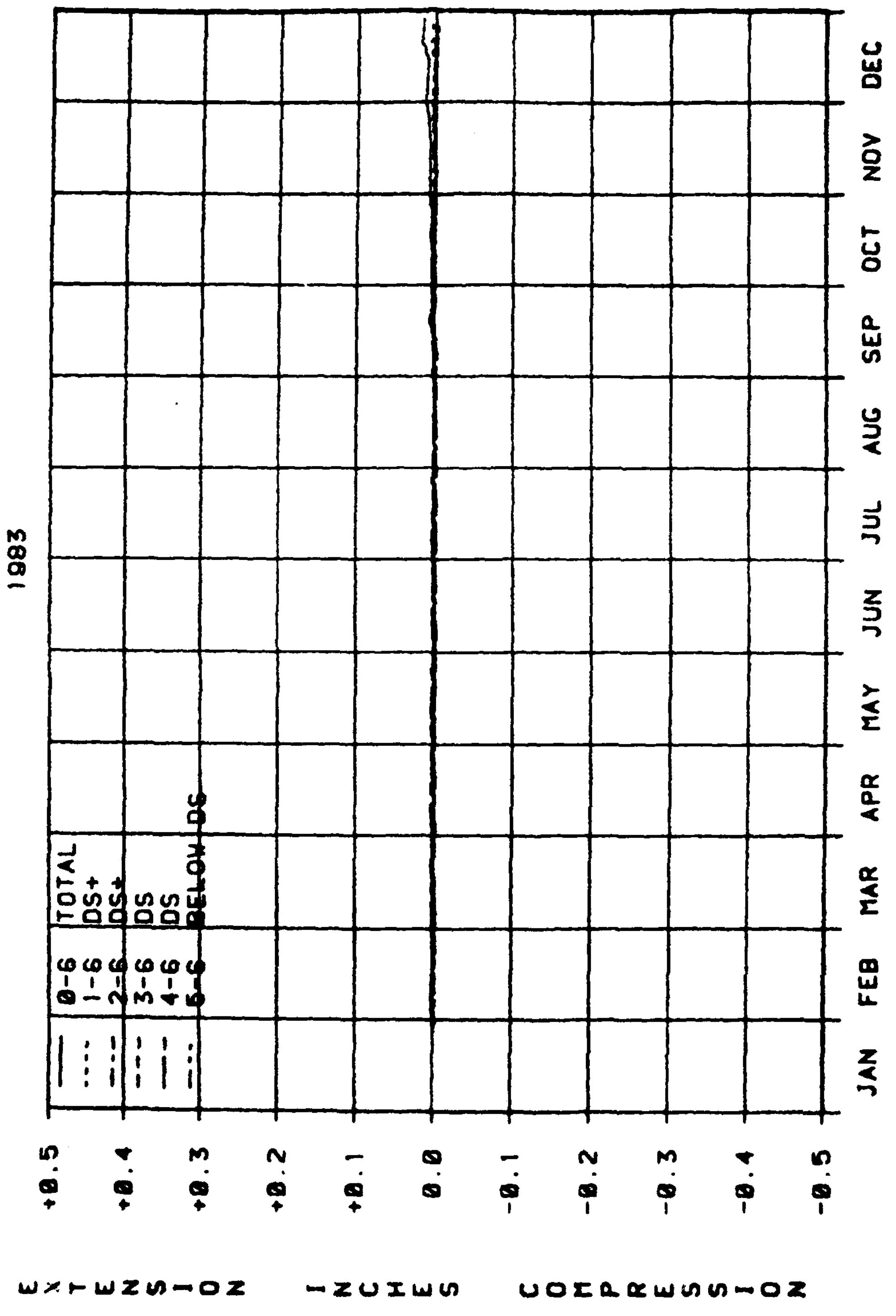
LIBBY LEFT BANK L14 (DELTA DISPLACEMENT)



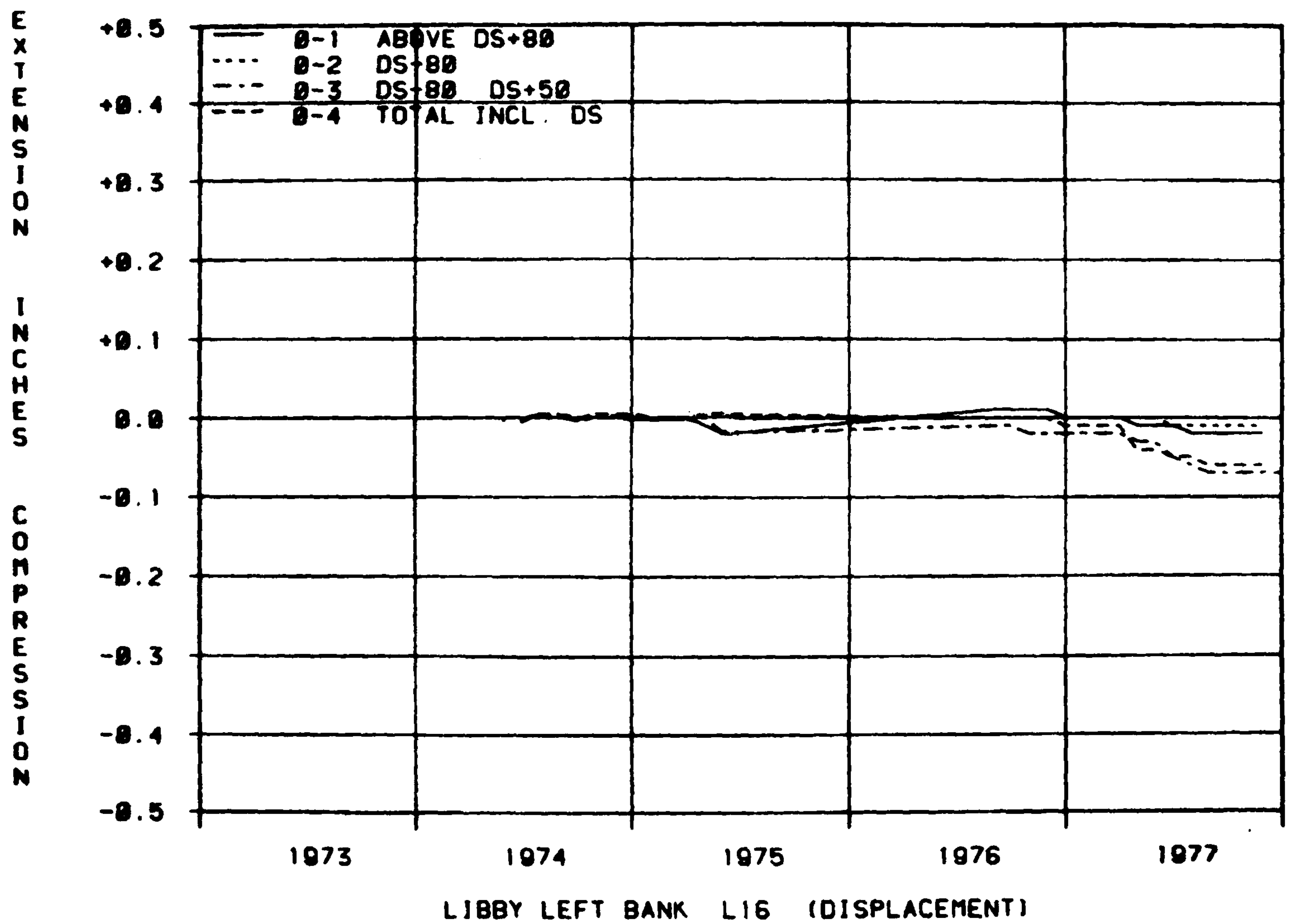
LIBBY LEFT BANK L14 (FLOATING HEAD)
0-6 TOTAL
1-6 DS
2-6 DS
3-6 DS
4-6 DS
5-6 BELOW DS
1973
1974
1975
1976
1977
+0.5
+0.4
+0.3
+0.2
+0.1
0.0
-0.1
-0.2
-0.3
-0.4
-0.5
EXTENSION INCHES COMPRESSION



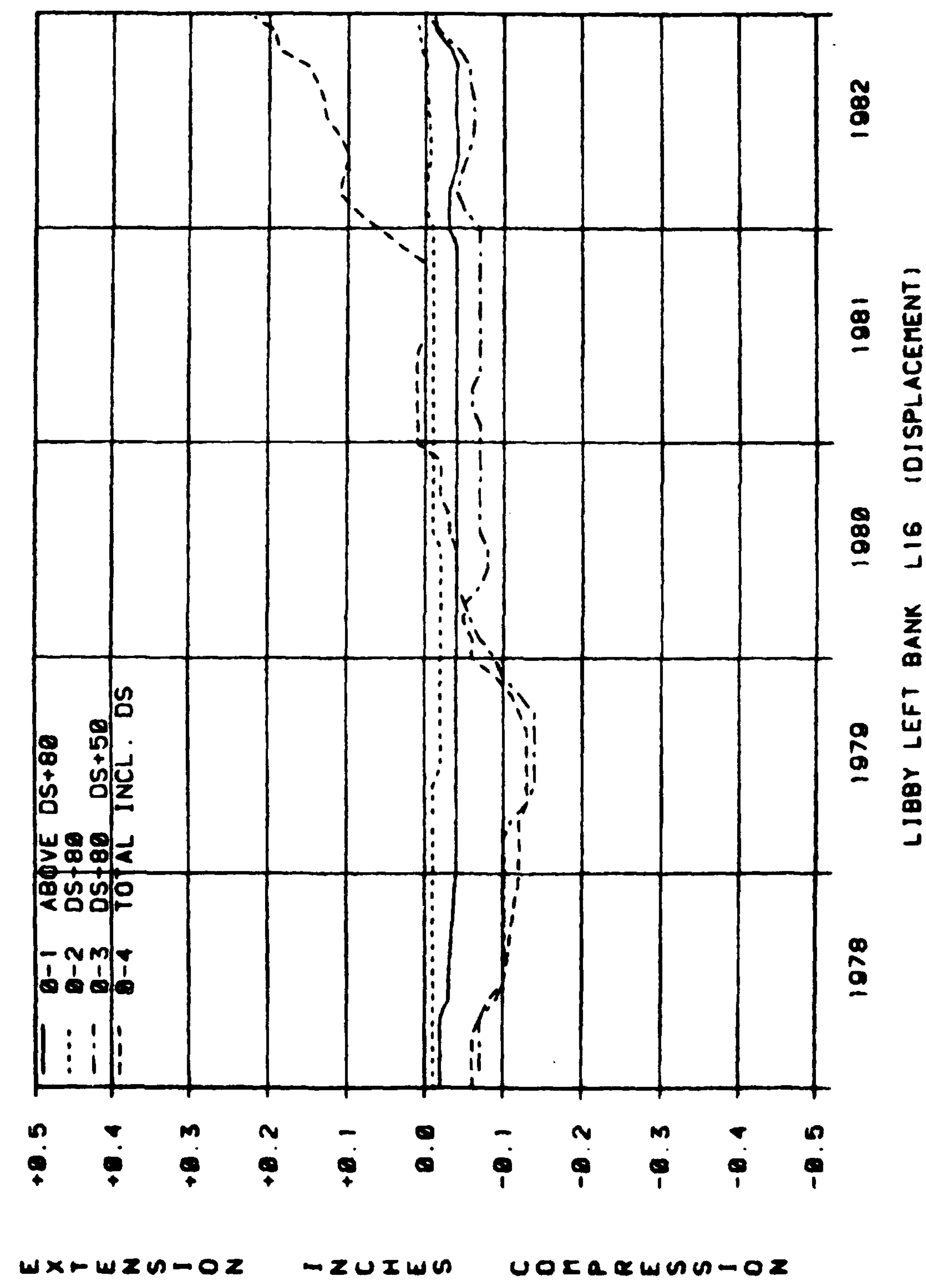
LIBBY LEFT BANK L14 (FLOATING HEAD)



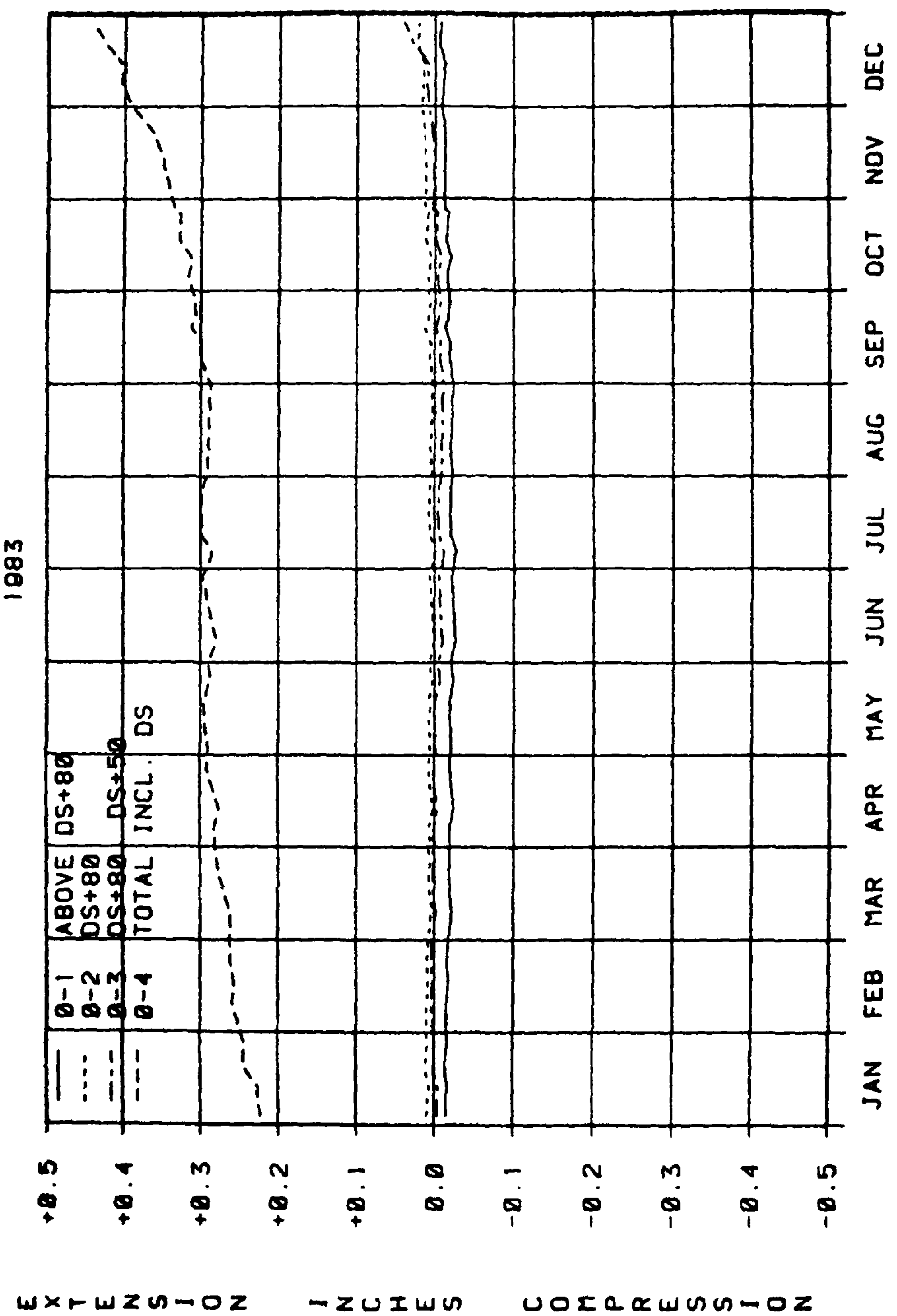
LIBBY LEFT BANK L14 (FLOATING HEAD)



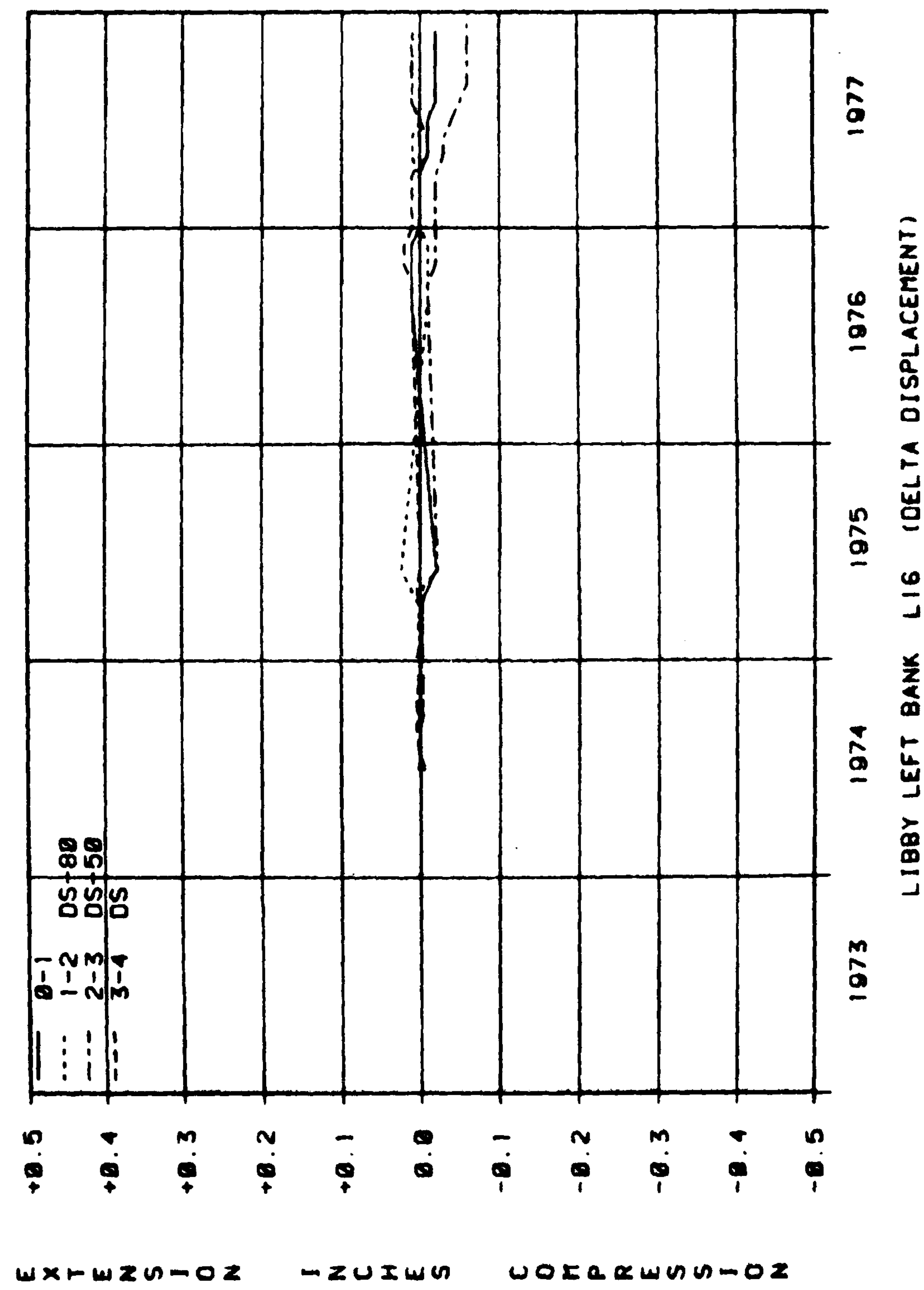
EXTENSION INCHES COMPRESSION
+0.5
+0.4
+0.3
+0.2
+0.1
0.0
-0.1
-0.2
-0.3
-0.4
-0.5
0-1 ABOVE DS+80
0-2 DS+80
0-3 DS+80 DS+50
0-4 TOTAL INCL. DS
1973
1974
1975
1976
1977
LIBBY LEFT BANK L16 (DISPLACEMENT)

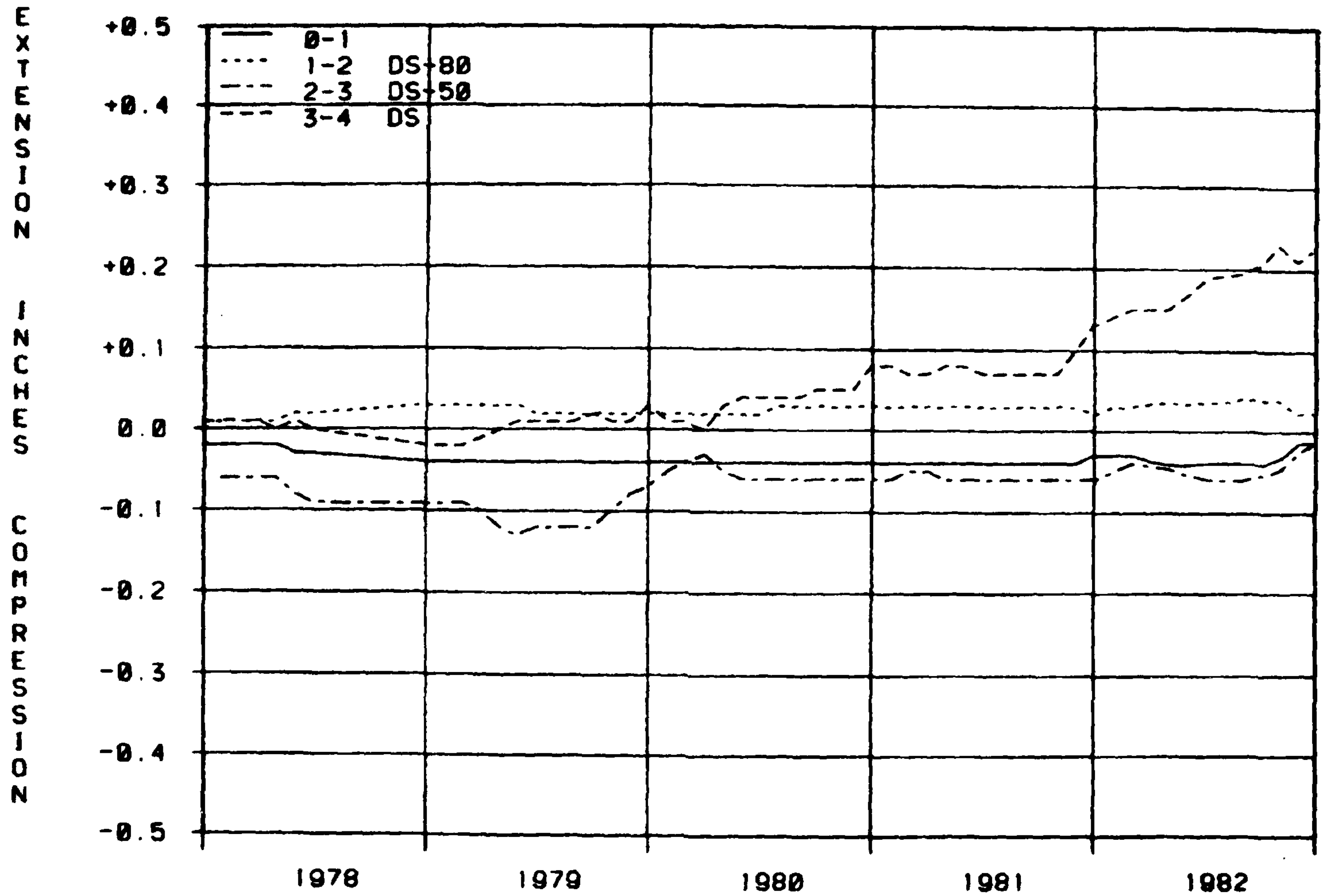


Ø-1 ABØVE DS+8Ø
Ø-2 DS-8Ø
Ø-3 DS-8Ø DS+5Ø
Ø-4 TOTAL INCL. DS
+Ø.5
+Ø.4
+Ø.3
+Ø.2
+Ø.1
Ø.Ø
-Ø.1
-Ø.2
-Ø.3
-Ø.4
-Ø.5
EXTENSION
INCHES
COMPRESSION
1978
1979
198Ø
1981
1982
LIBBY LEFT BANK L16 (DISPLACEMENT)

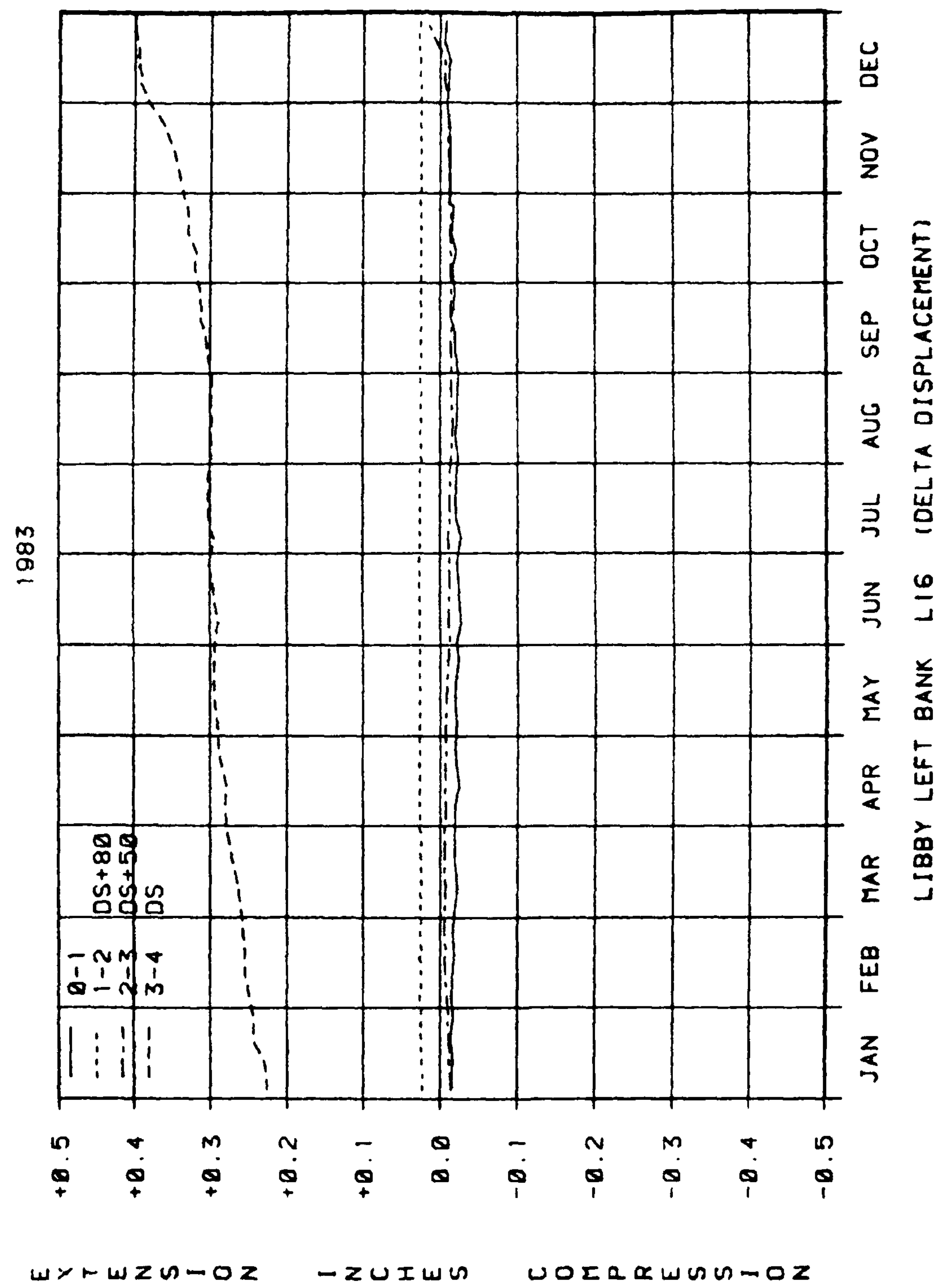


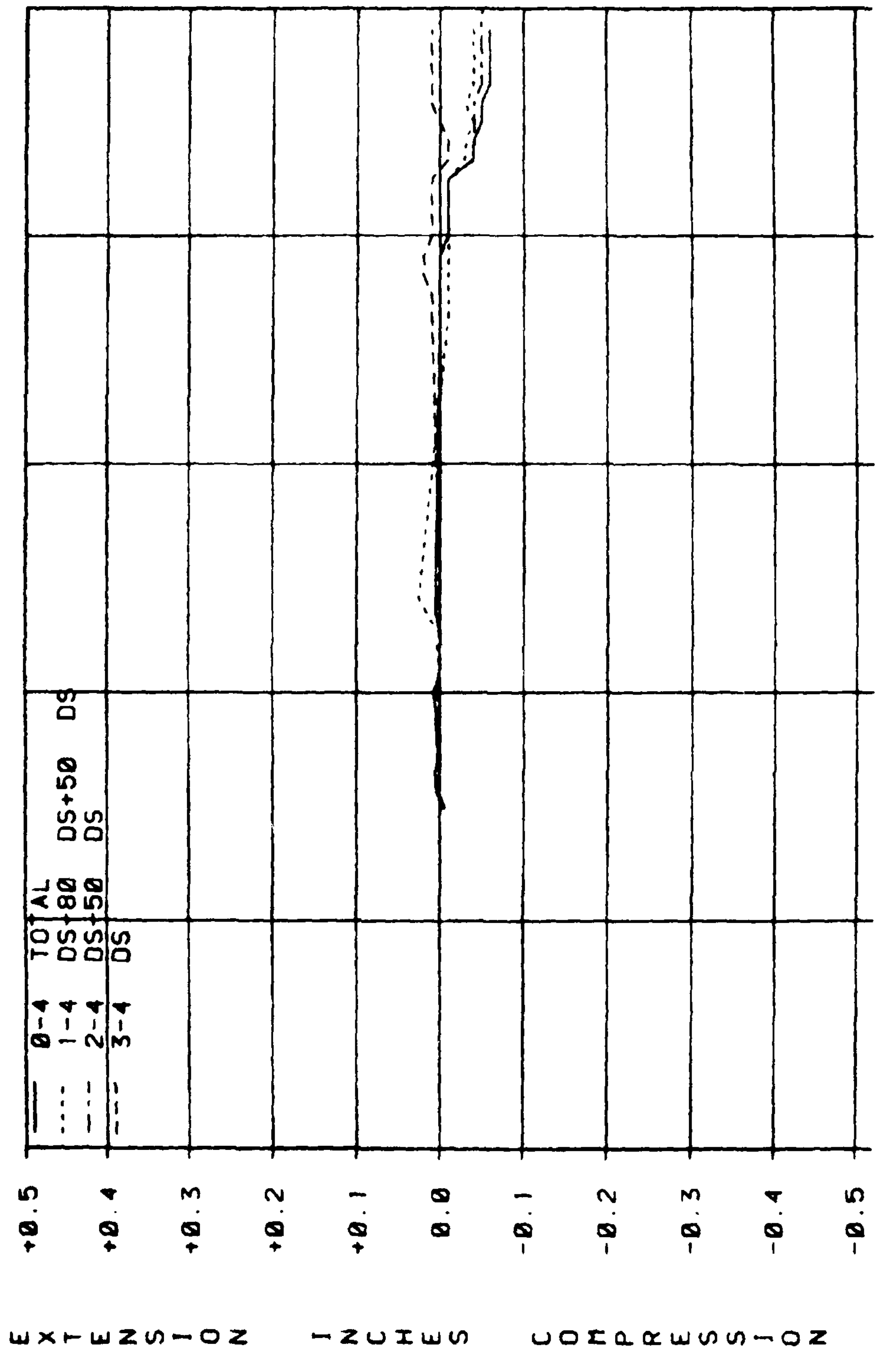
LIBBY LEFT BANK L16 (DISPLACEMENT)


LIBBY LEFT BANK L16 (DELTA DISPLACEMENT)
0-1
1-2 DS-80
2-3 DS-50
3-4 DS
1973
1974
1975
1976
1977
+0.5
+0.4
+0.3
+0.2
+0.1
0.0
-0.1
-0.2
-0.3
-0.4
-0.5
EXTENSION INCHES COMPRESSION

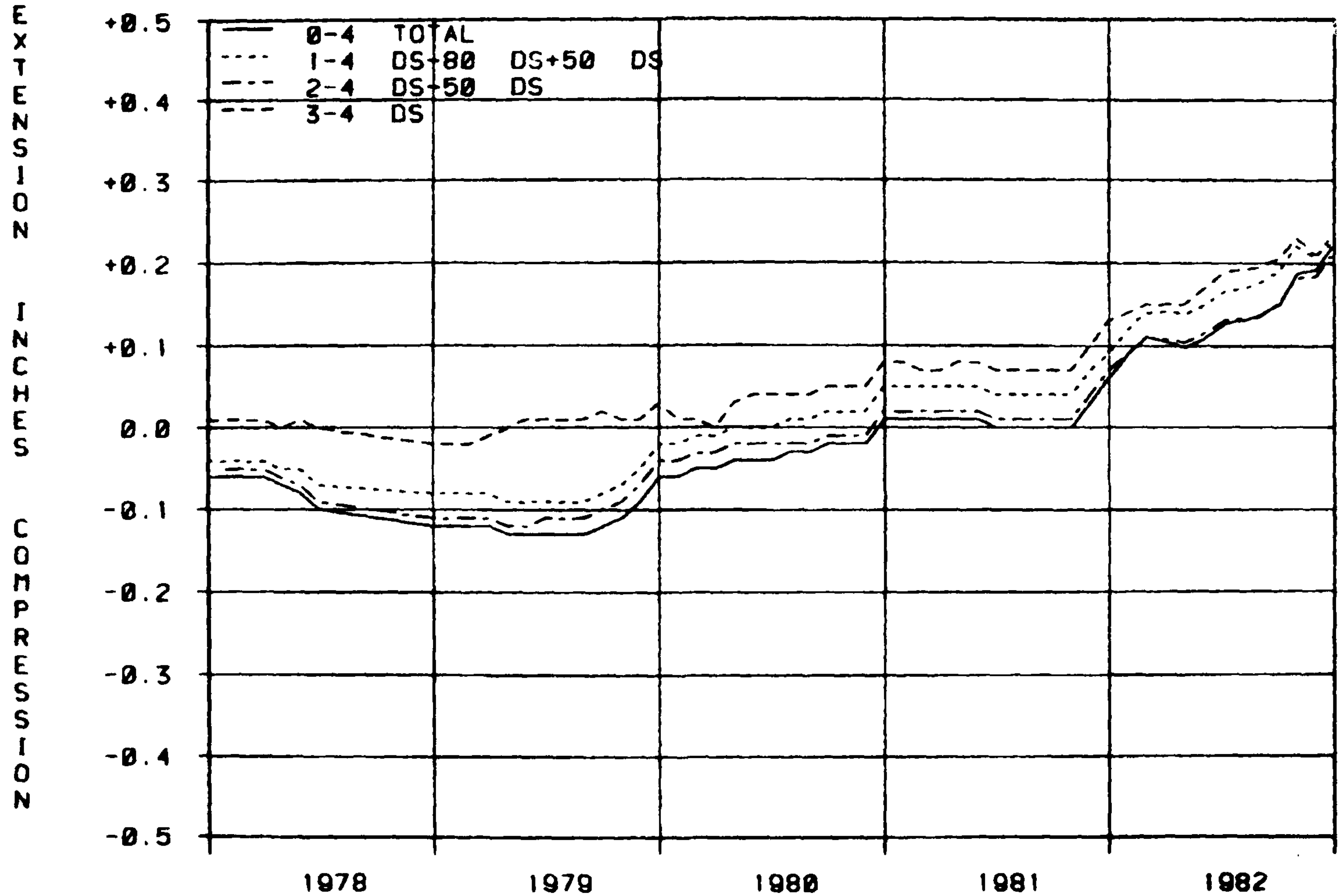


LIBBY LEFT BANK L16 (DELTA DISPLACEMENT)


1983
0-1
1-2 DS+80
2-3 DS+50
3-4 DS
JAN FEB MAR APR MAY JUN JUL AUG SEP OCT NOV DEC
LIBBY LEFT BANK L16 (DELTA DISPLACEMENT)
+0.5 +0.4 +0.3 +0.2 +0.1 0.0 -0.1 -0.2 -0.3 -0.4 -0.5
EXTENSION INCHES COMPRESSION

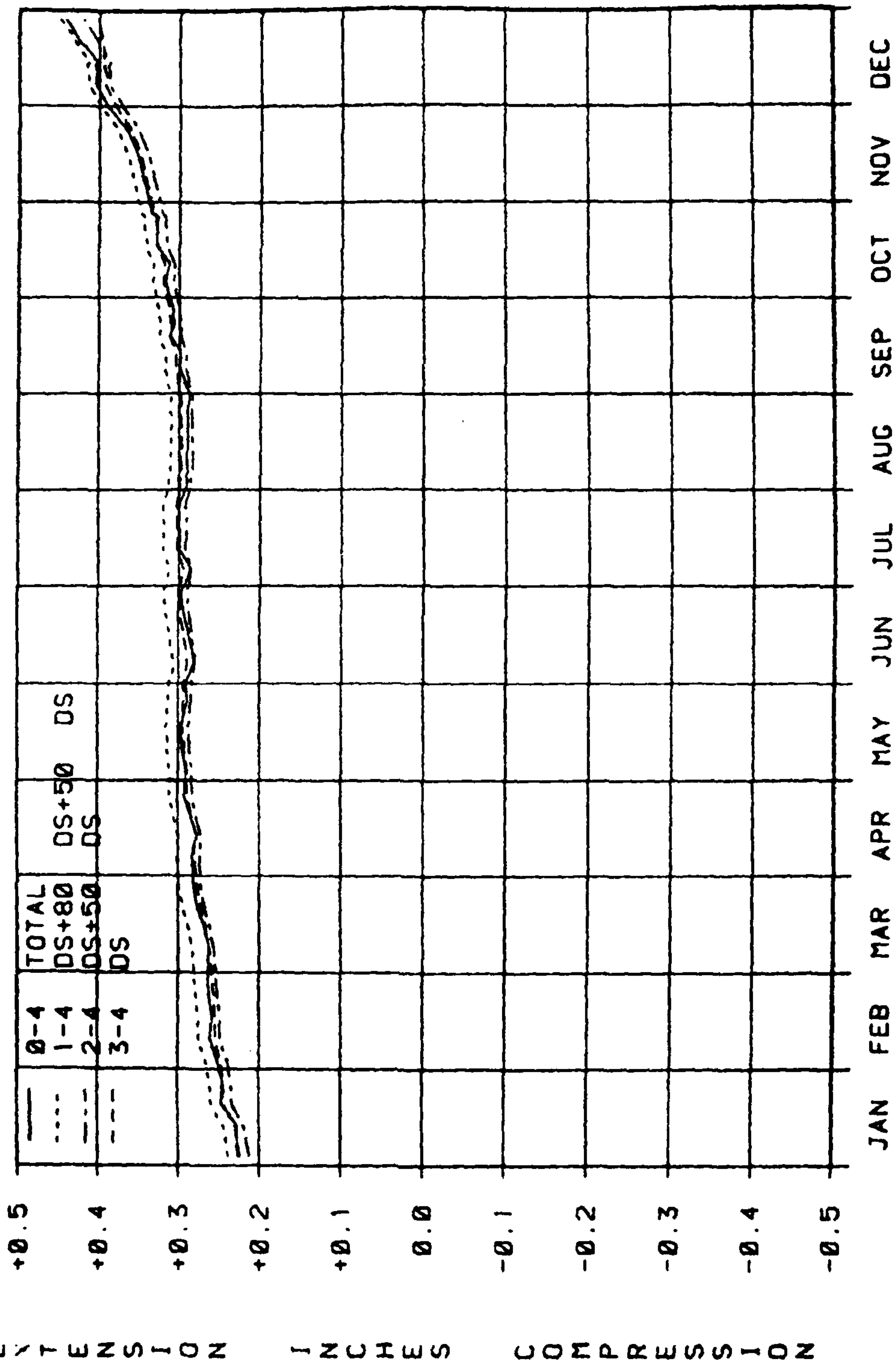


LIBBY LEFT BANK L16 (FLOATING HEAD)

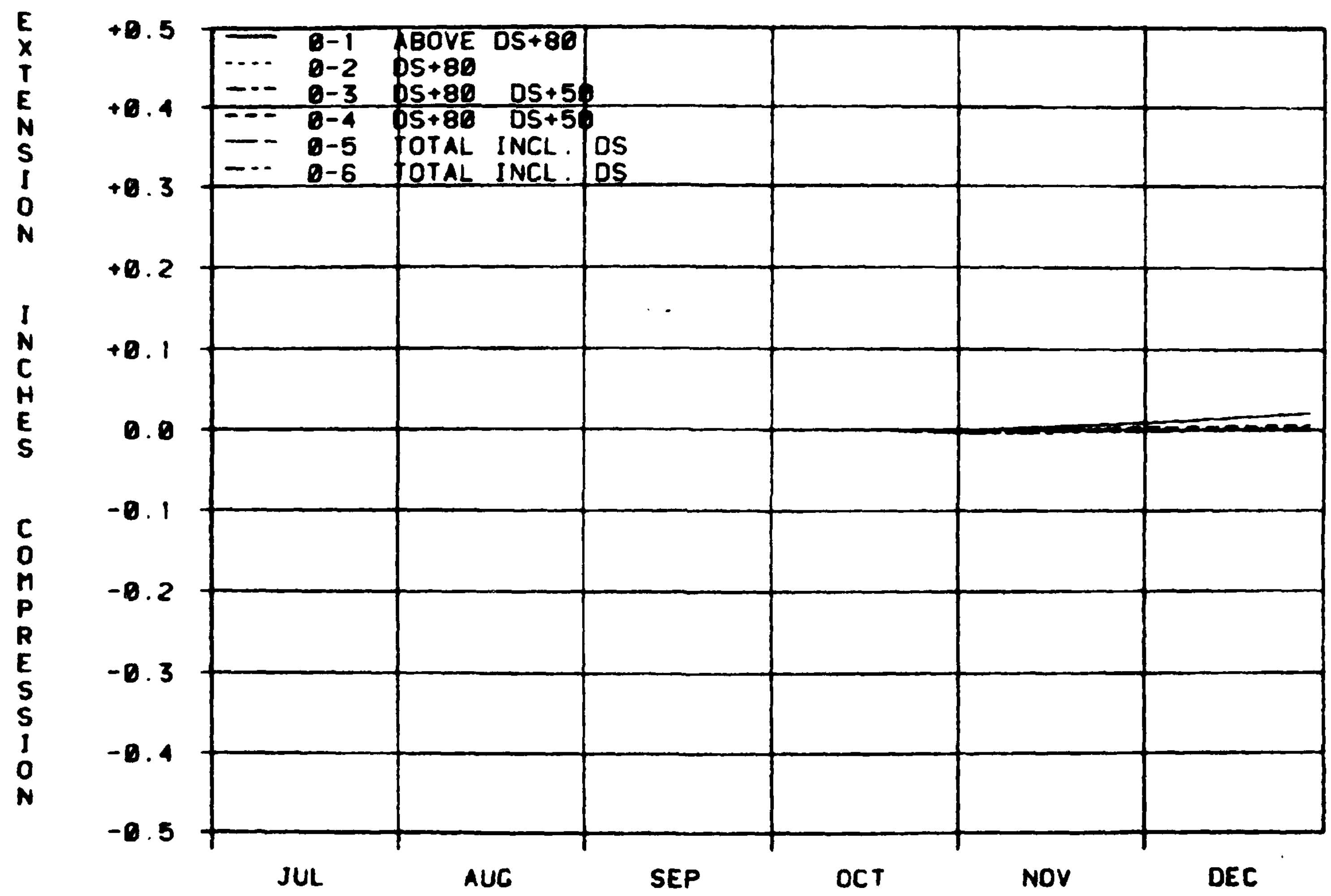


LIBBY LEFT BANK L16 (FLOATING HEAD)

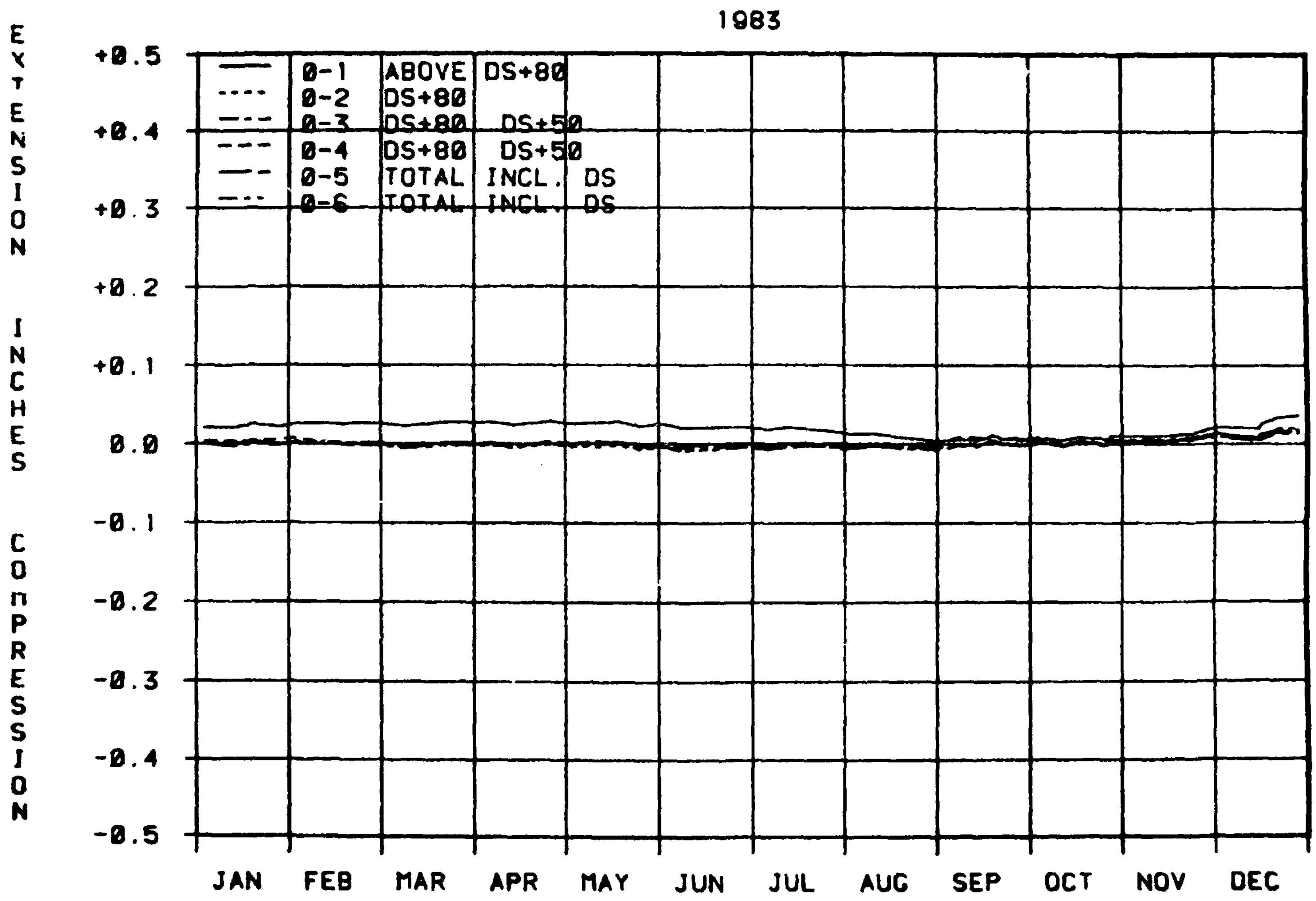
1983



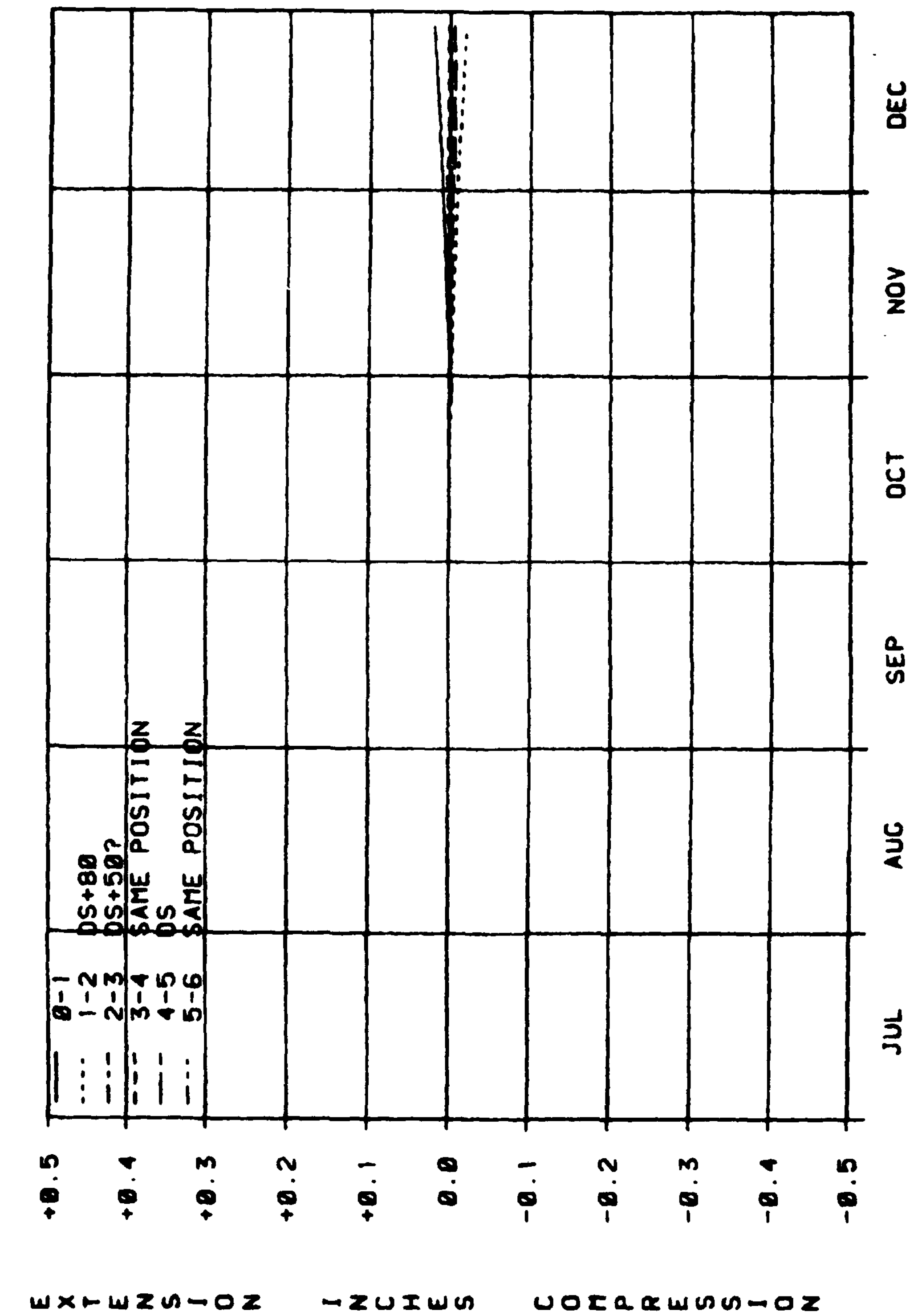
LIBBY LEFT BANK L16 (FLOATING HEAD)



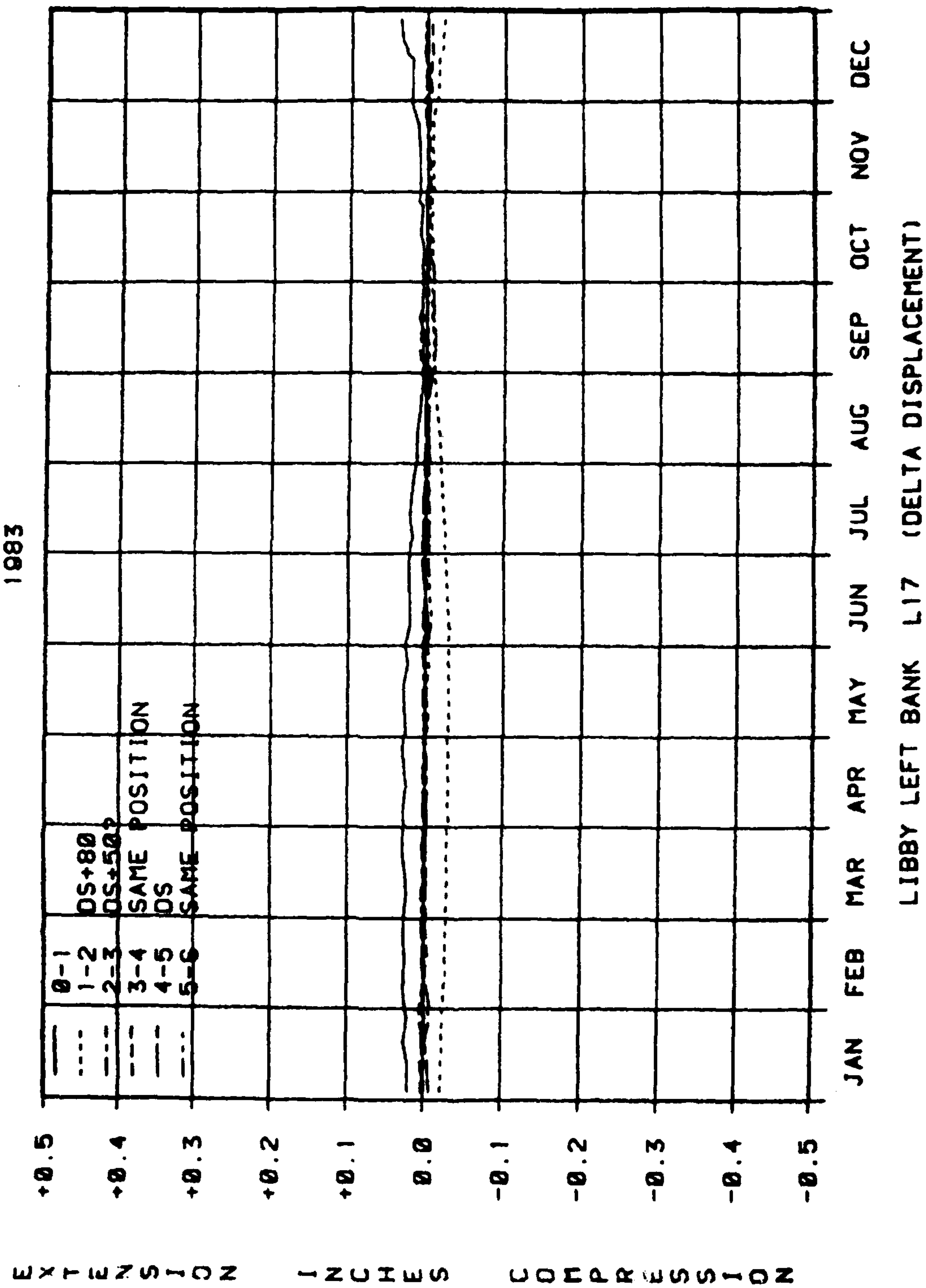
LIBBY LEFT BANK L17 (DISPLACEMENT) 1982

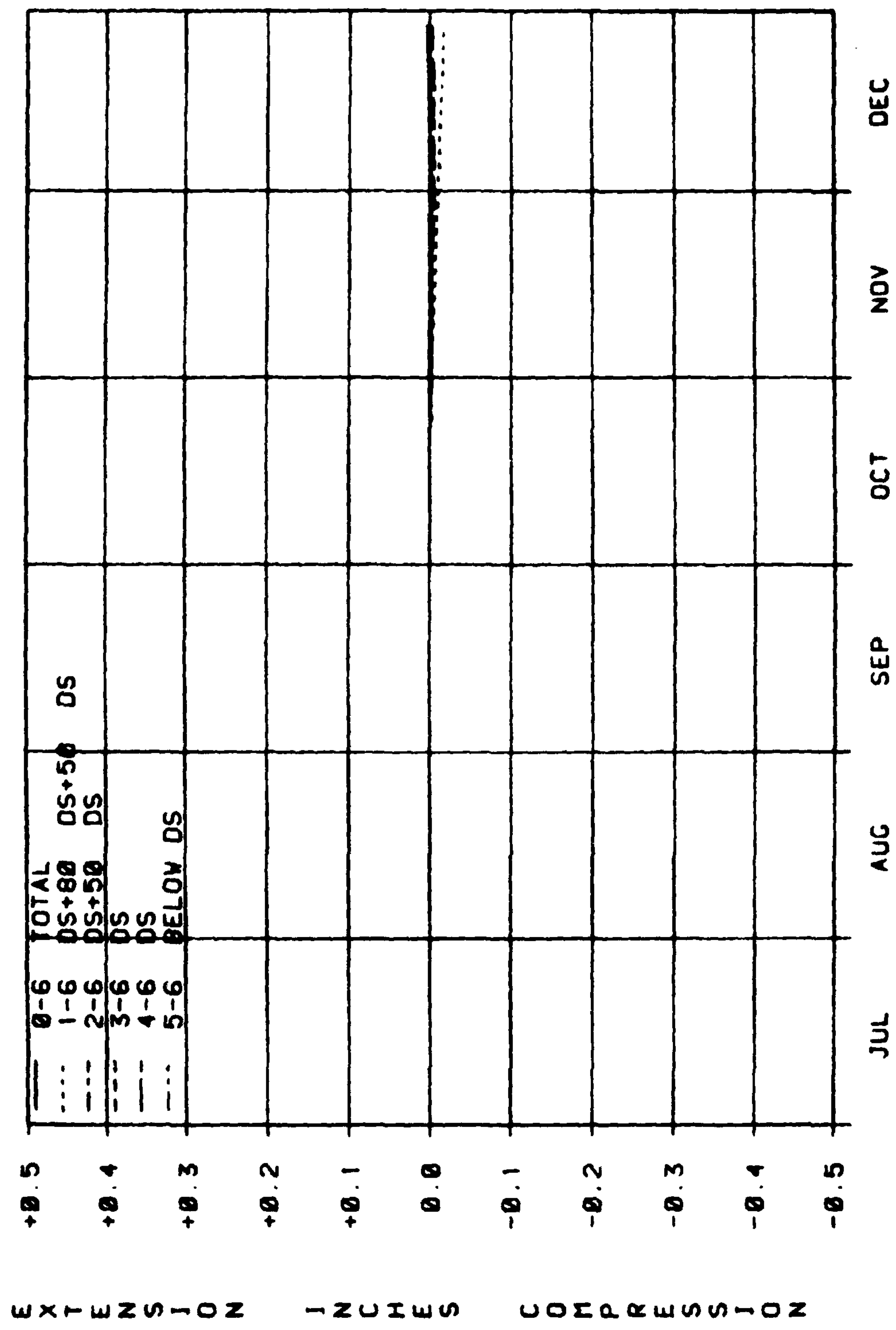


LIBBY LEFT BANK L17 (DISPLACEMENT)

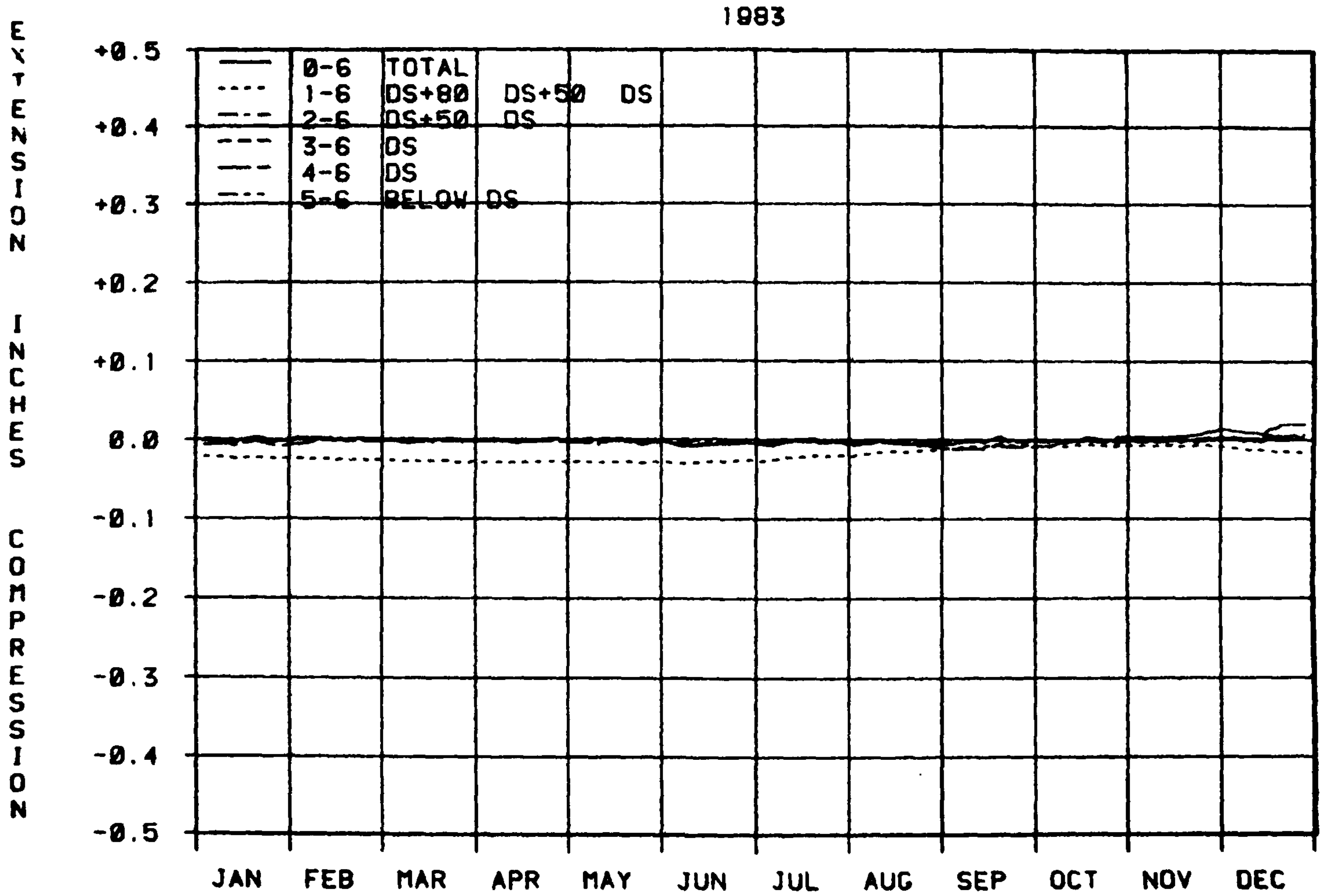


Ø-1
1-2 DS+8Ø
2-3 DS+5Ø?
3-4 SAME POSITION
4-5 DS
5-6 SAME POSITION
+Ø.5
+Ø.4
+Ø.3
+Ø.2
+Ø.1
Ø.Ø
-Ø.1
-Ø.2
-Ø.3
-Ø.4
-Ø.5
EXTENSION INCHES COMPRESSION
JUL
AUG
SEP
OCT
NOV
DEC
LIBBY LEFT BANK L17 (DELTA DISPLACEMENT) 1982

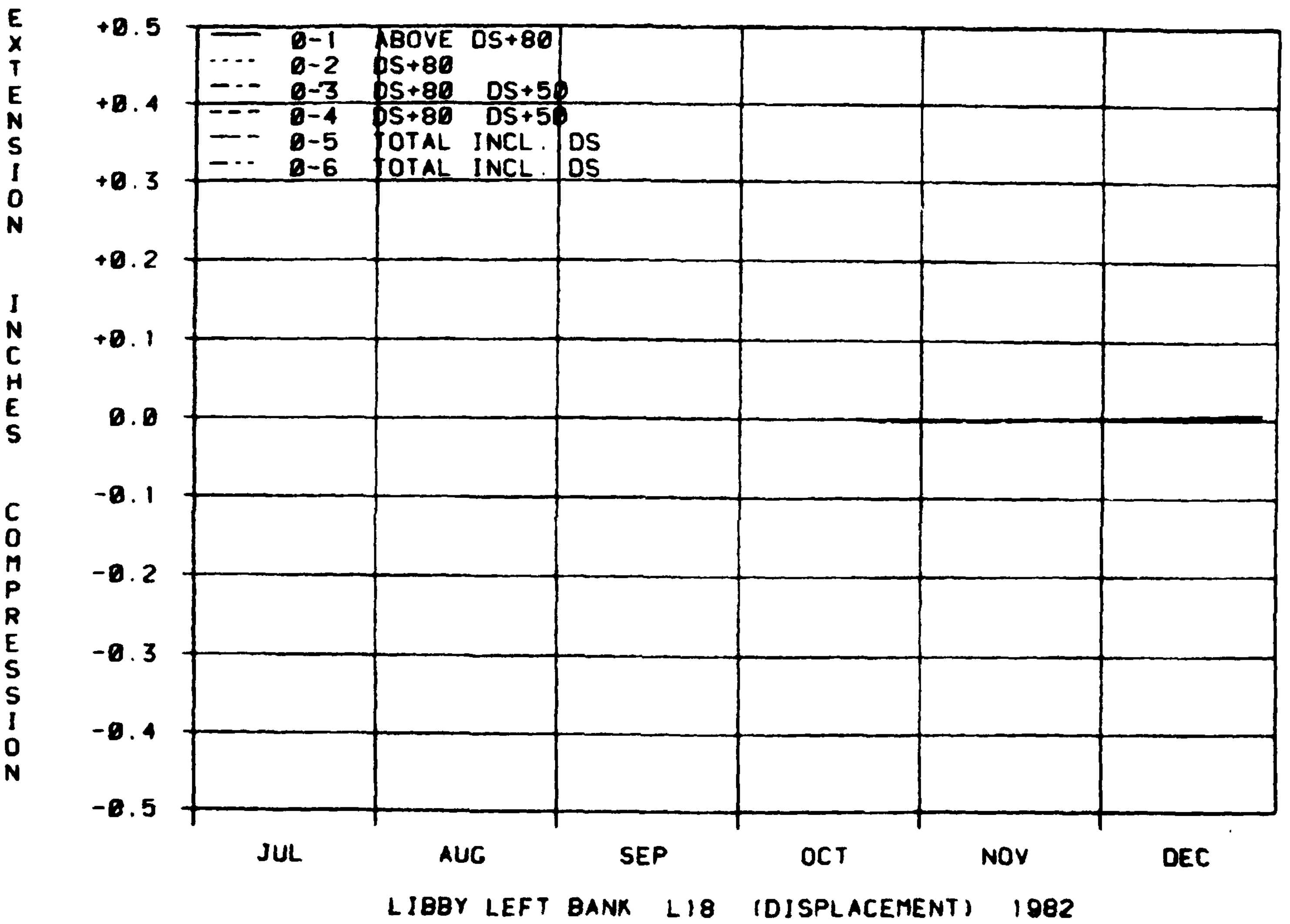

1983
0-1 DS+80
1-2 DS+50?
2-3 SAME POSITION
3-4 DS
4-5 SAME POSITION
5-6
+0.5
+0.4
+0.3
+0.2
+0.1
0.0
-0.1
-0.2
-0.3
-0.4
-0.5
EXTENSION INCHES COMPRESSION
JAN FEB MAR APR MAY JUN JUL AUG SEP OCT NOV DEC
LIBBY LEFT BANK L17 (DELTA DISPLACEMENT)

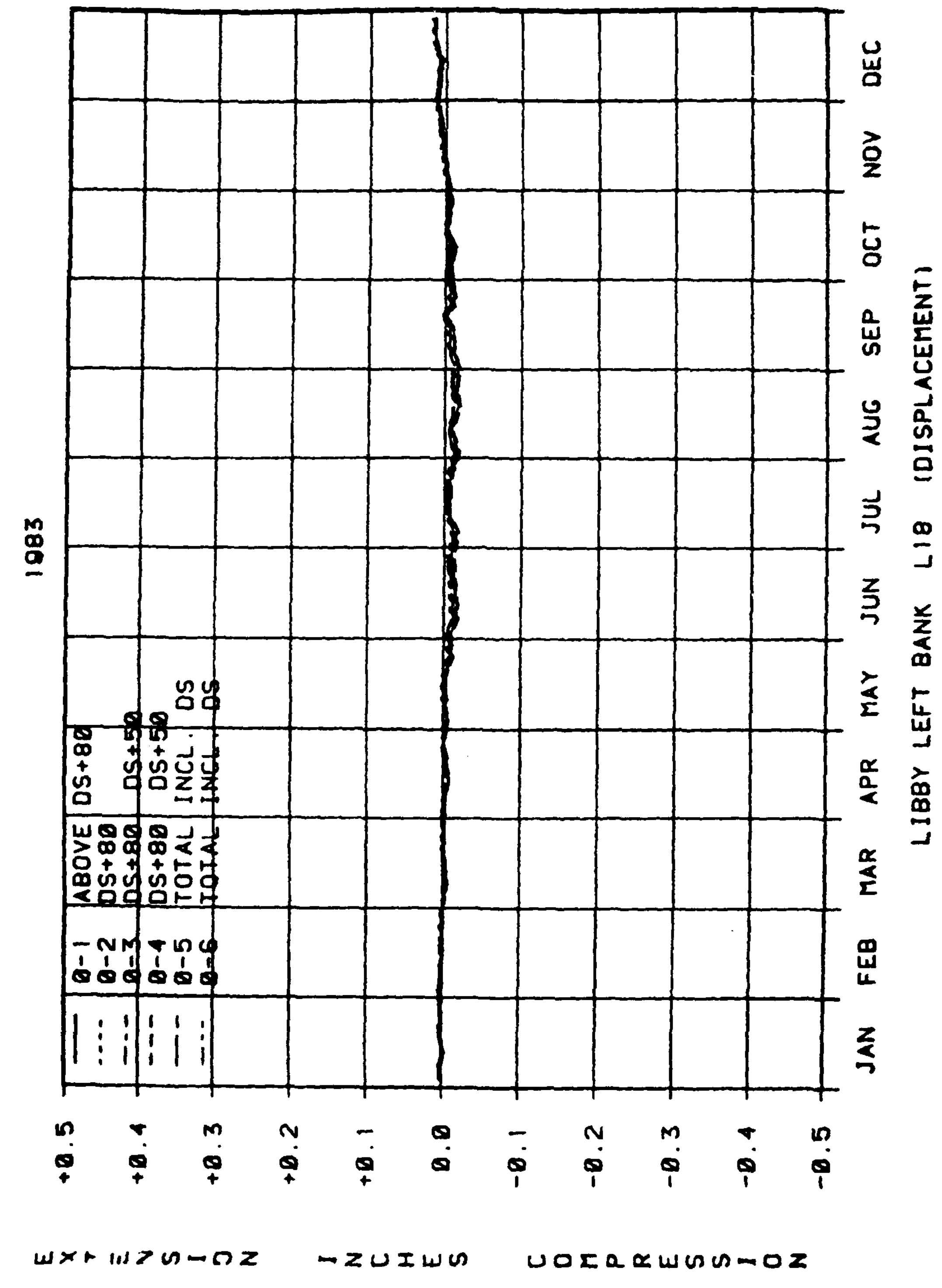


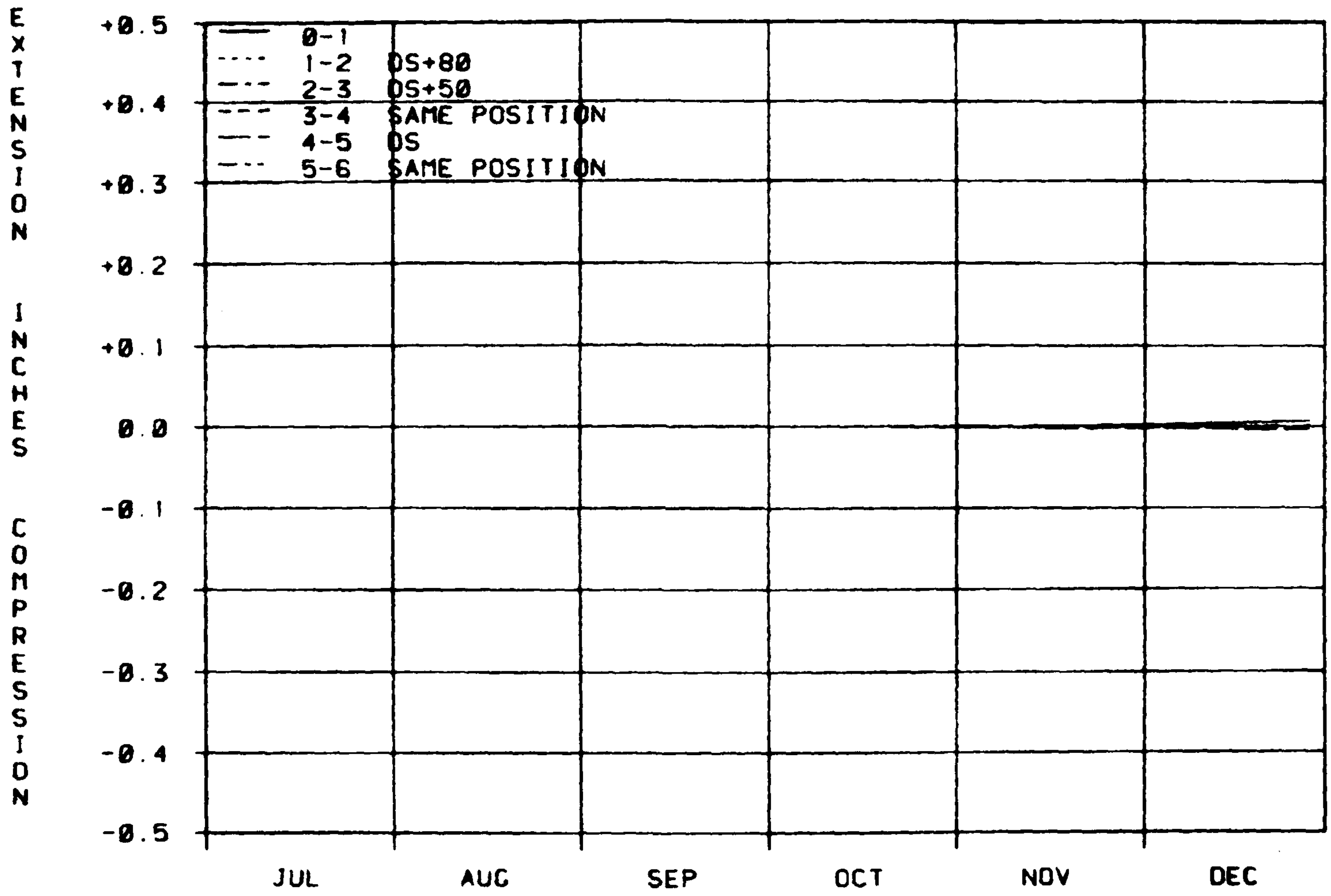
LIBBY LEFT BANK L17 (FLOATING HEAD) 1982



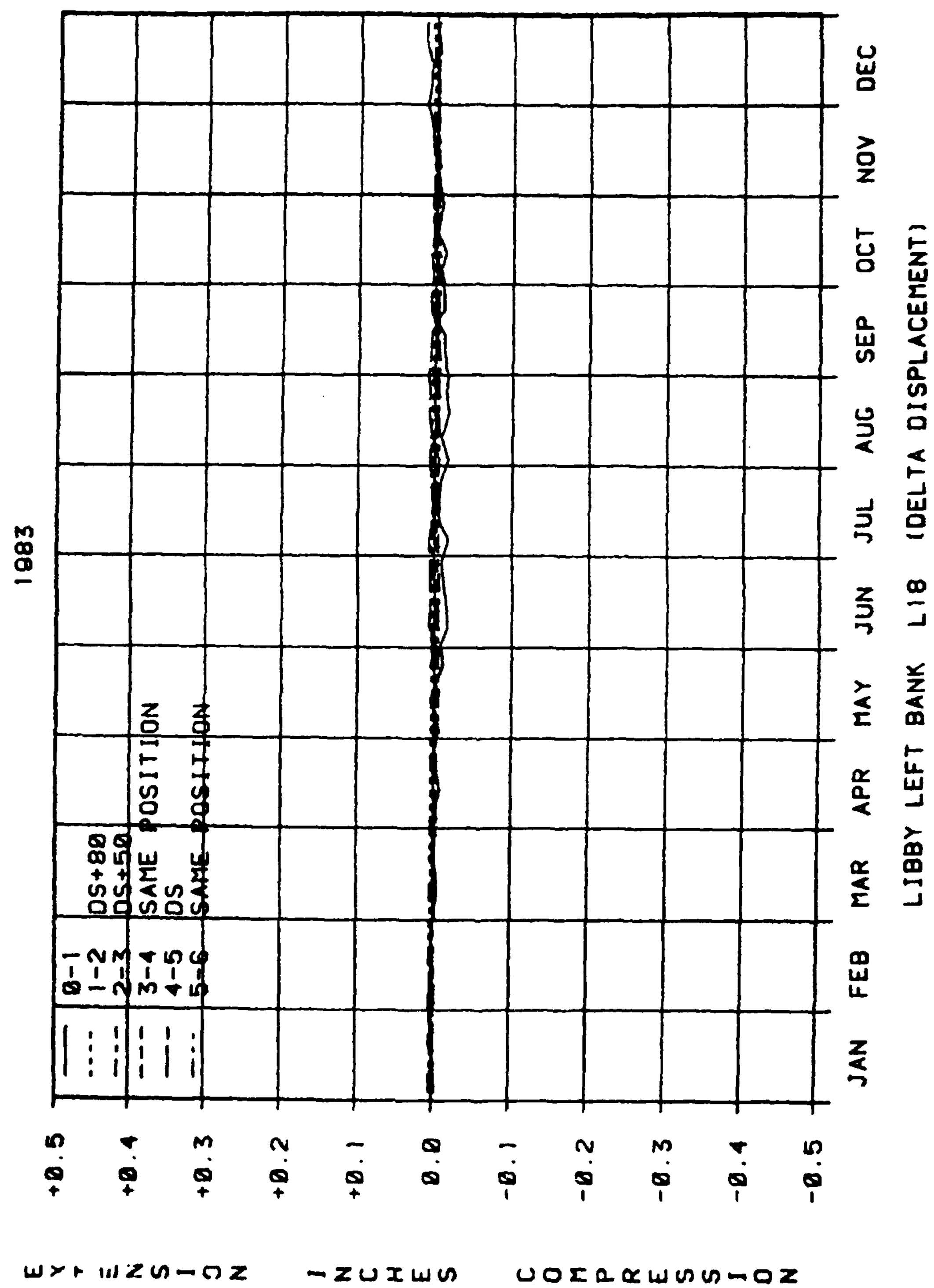
LIBBY LEFT BANK L17 (FLOATING HEAD)

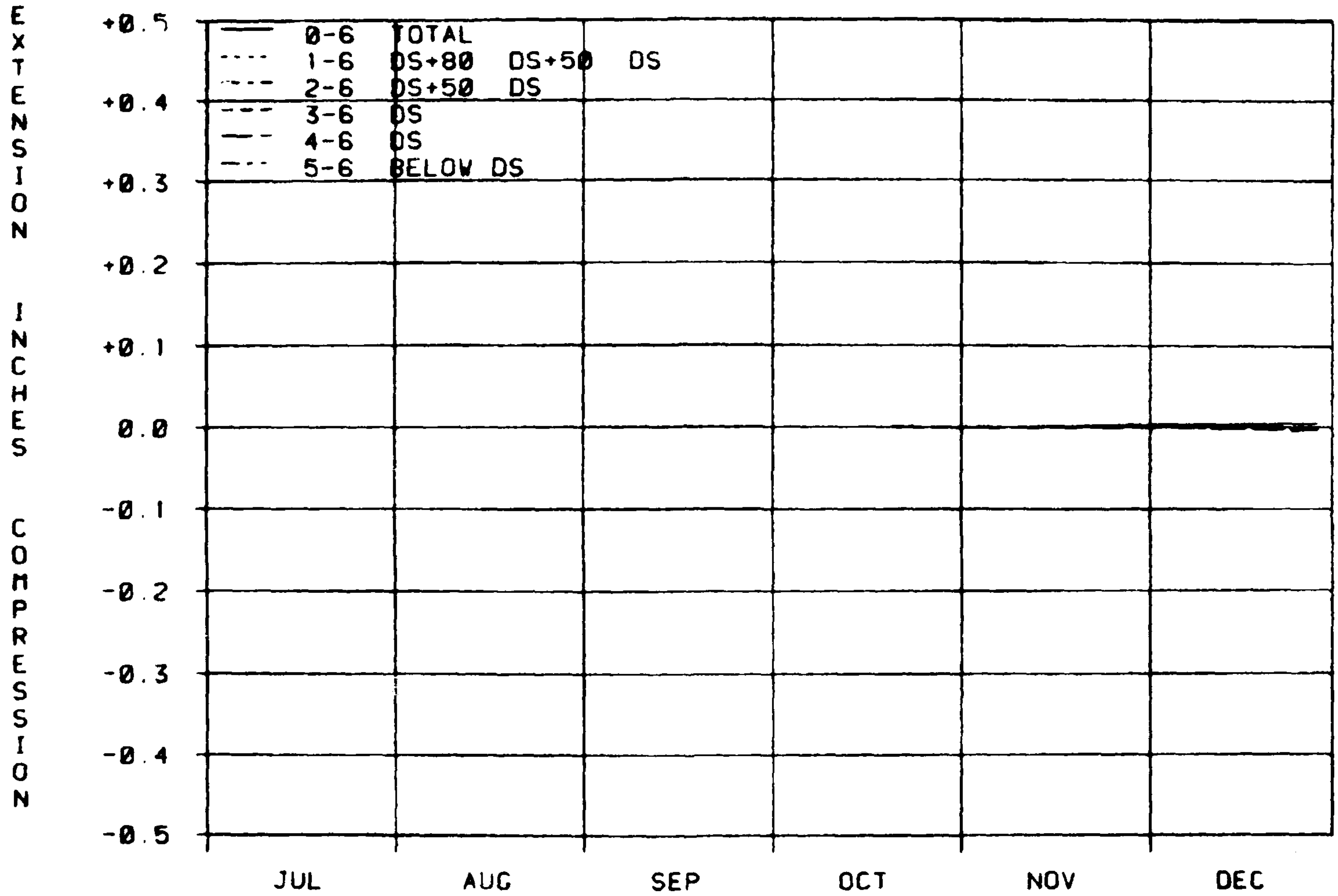

EXTENSION INCHES COMPRESSION
+0.5
+0.4
+0.3
+0.2
+0.1
0.0
-0.1
-0.2
-0.3
-0.4
-0.5
0-1 ABOVE DS+80
0-2 DS+80
0-3 DS+80 DS+50
0-4 DS+80 DS+50
0-5 TOTAL INCL. DS
0-6 TOTAL INCL. DS
JUL
AUG
SEP
OCT
NOV
DEC
LIBBY LEFT BANK L18 (DISPLACEMENT) 1982


1983
0-1 ABOVE DS+80
0-2 DS+80
0-3 DS+80 DS+50
0-4 DS+80 DS+50
0-5 TOTAL INCL. DS
0-6 TOTAL INCL. DS
+0.5
+0.4
+0.3
+0.2
+0.1
0.0
-0.1
-0.2
-0.3
-0.4
-0.5
EXTENSION INCHES COMPRESSION
JAN FEB MAR APR MAY JUN JUL AUG SEP OCT NOV DEC
LIBBY LEFT BANK L18 (DISPLACEMENT)

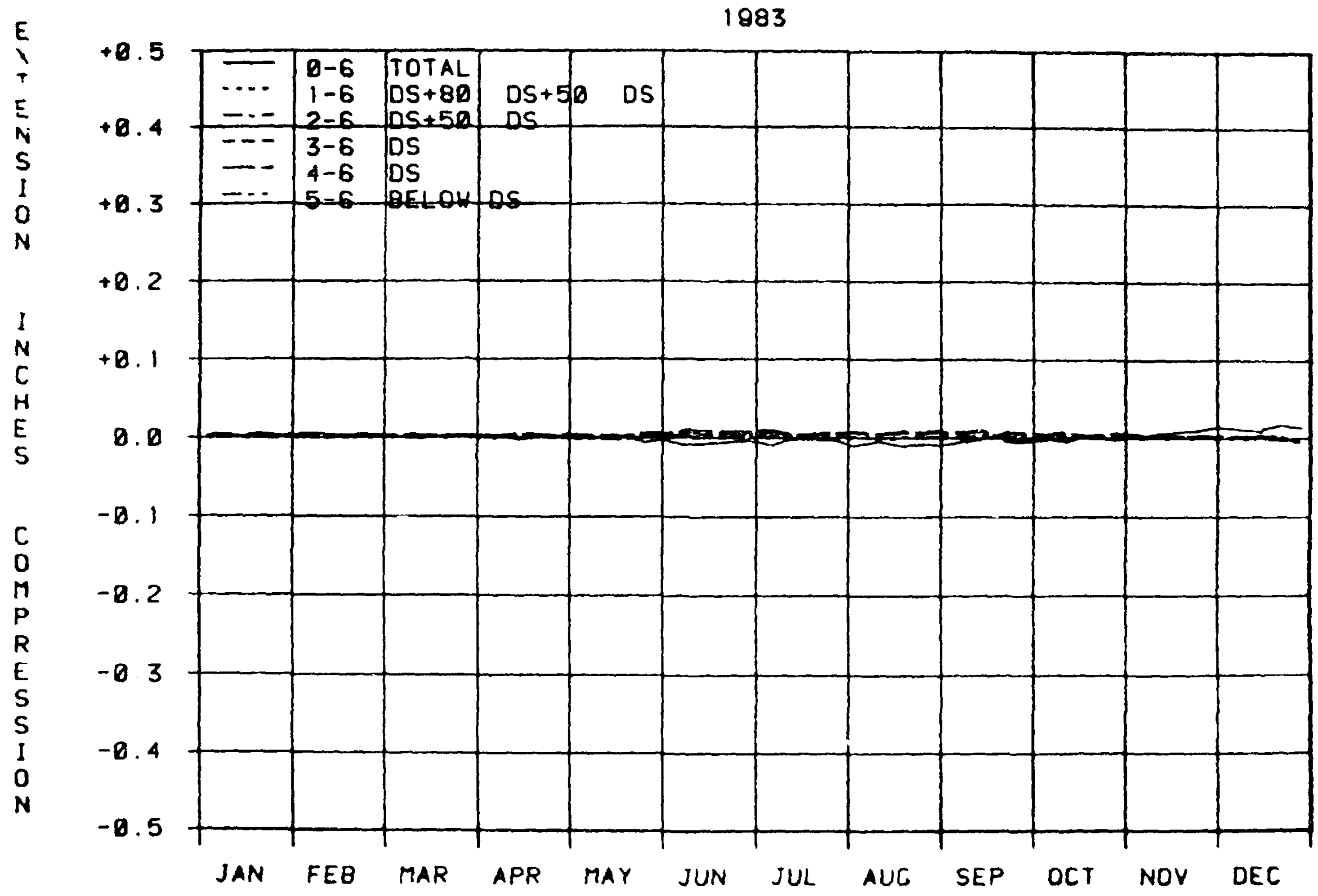


LIBBY LEFT BANK L18 (DELTA DISPLACEMENT) 1982


1983
0-1
1-2 DS+80
2-3 DS+50
3-4 SAME POSITION
4-5 DS
5-6 SAME POSITION
+0.5
+0.4
+0.3
+0.2
+0.1
0.0
-0.1
-0.2
-0.3
-0.4
-0.5
EXTENSION INCHES COMPRESSION
JAN FEB MAR APR MAY JUN JUL AUG SEP OCT NOV DEC
LIBBY LEFT BANK L18 (DELTA DISPLACEMENT)

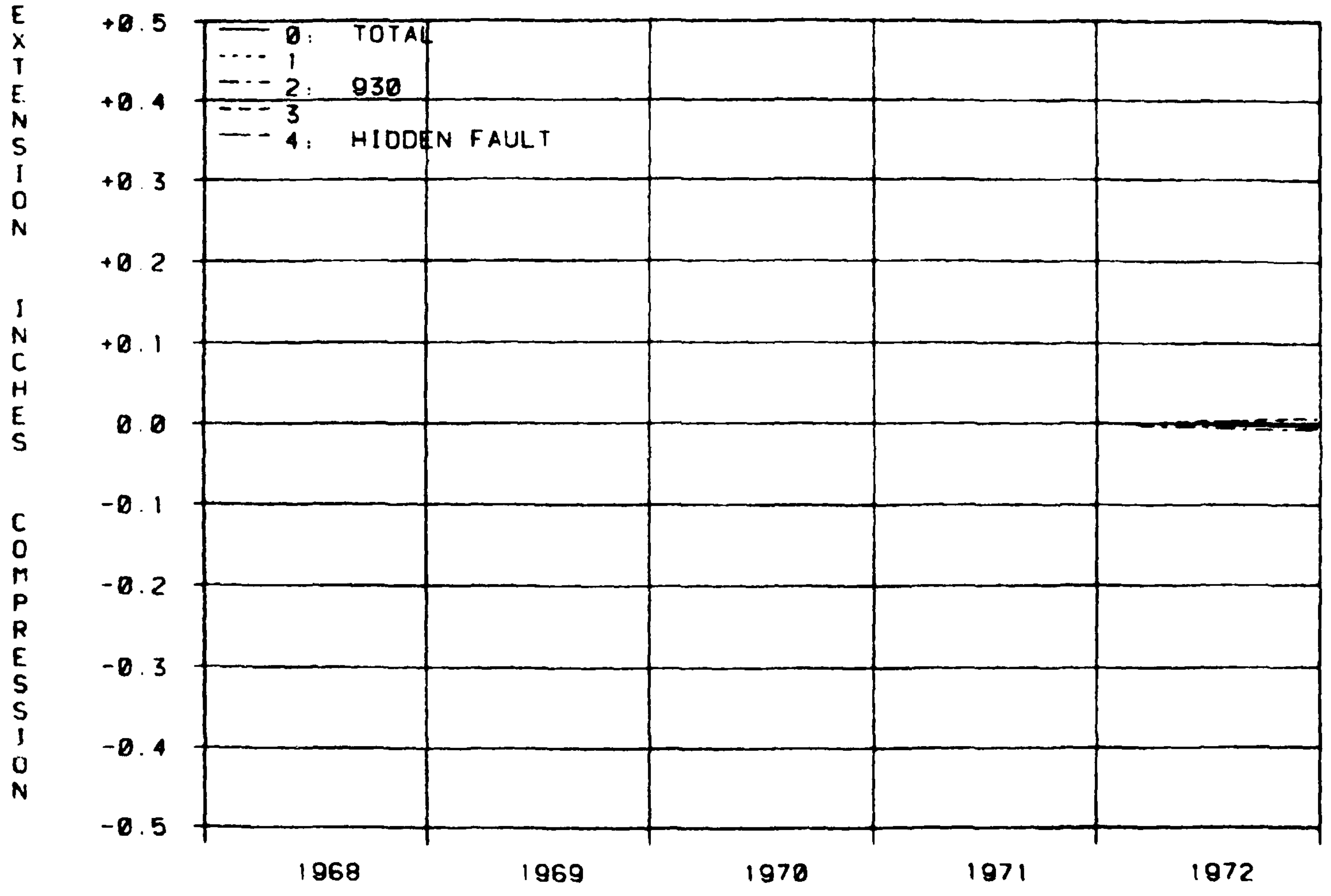


LIBBY LEFT BANK L18 (FLOATING HEAD) 1982

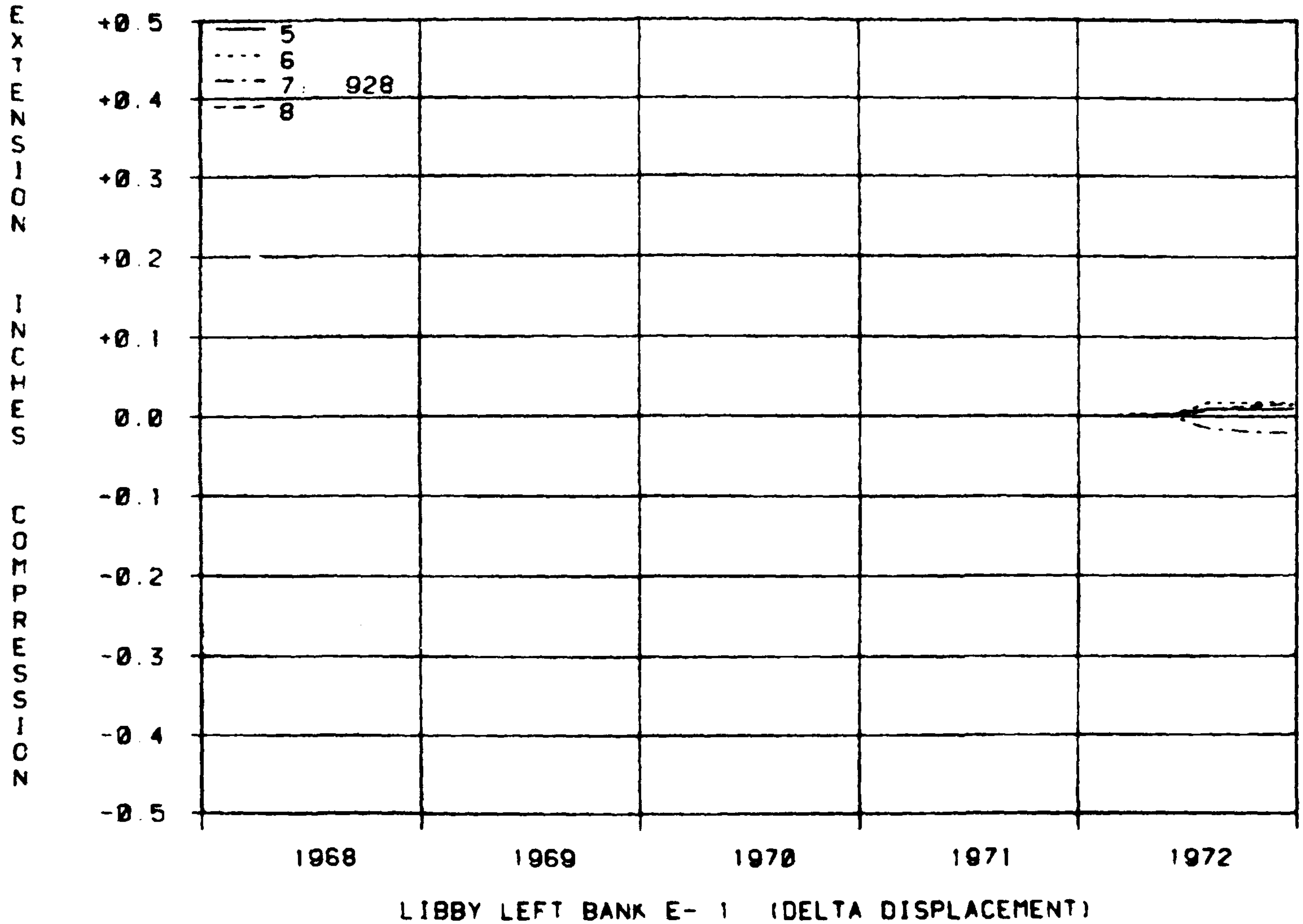


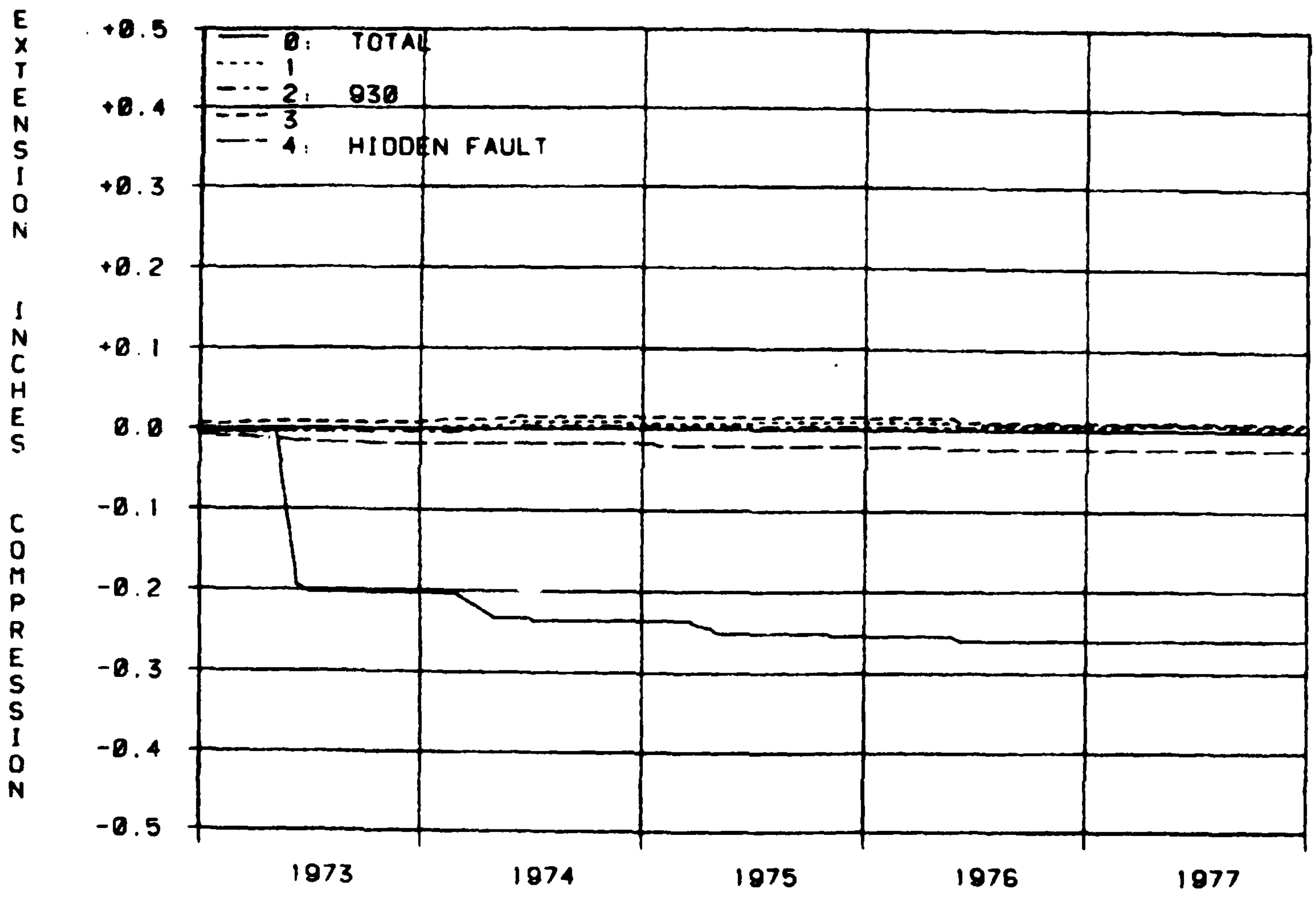
LIBBY LEFT BANK L18 (FLOATING HEAD)

Appendix C - Instrumental Plots - E Extensometers

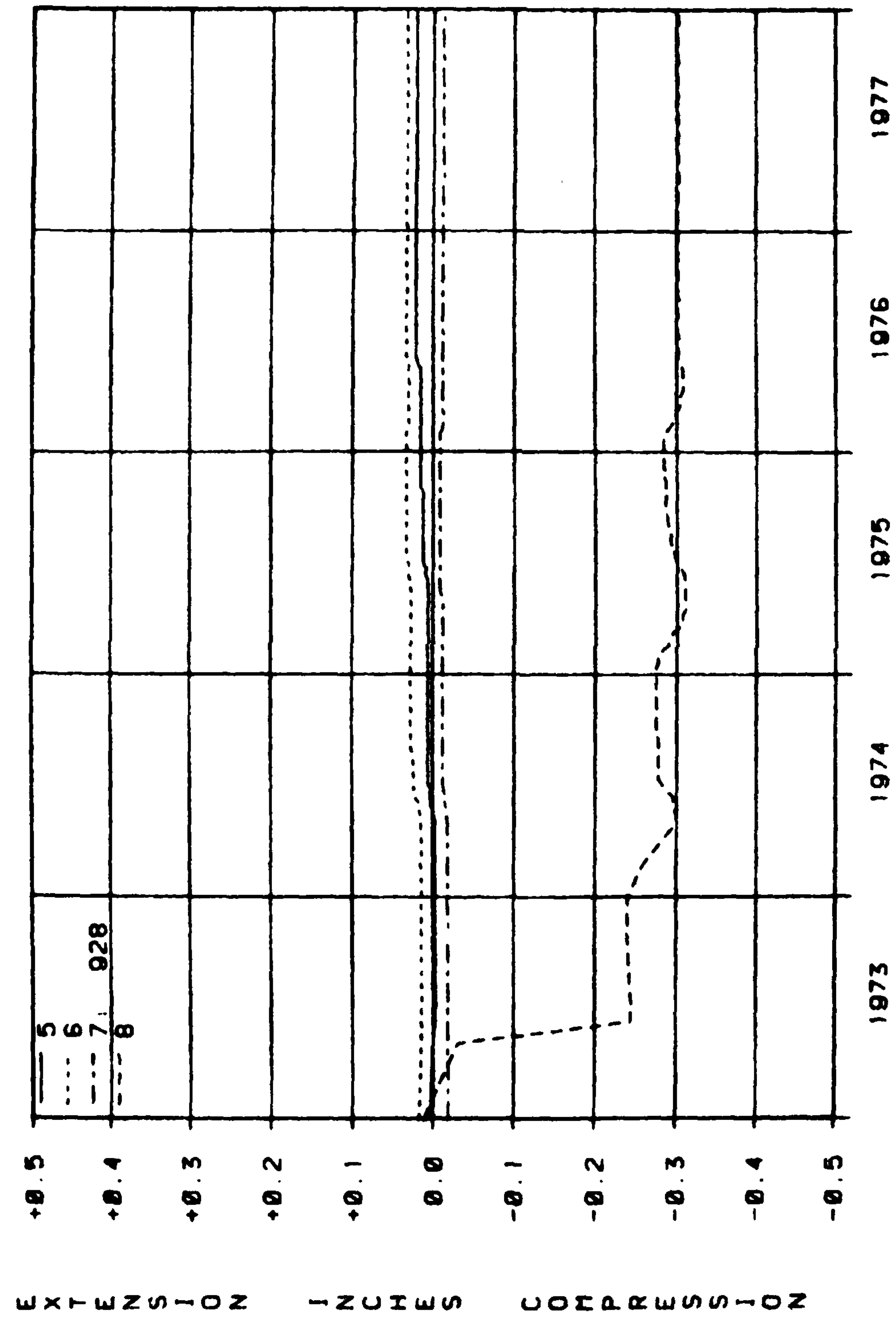


LIBBY LEFT BANK E- 1 (DELTA DISPLACEMENT)

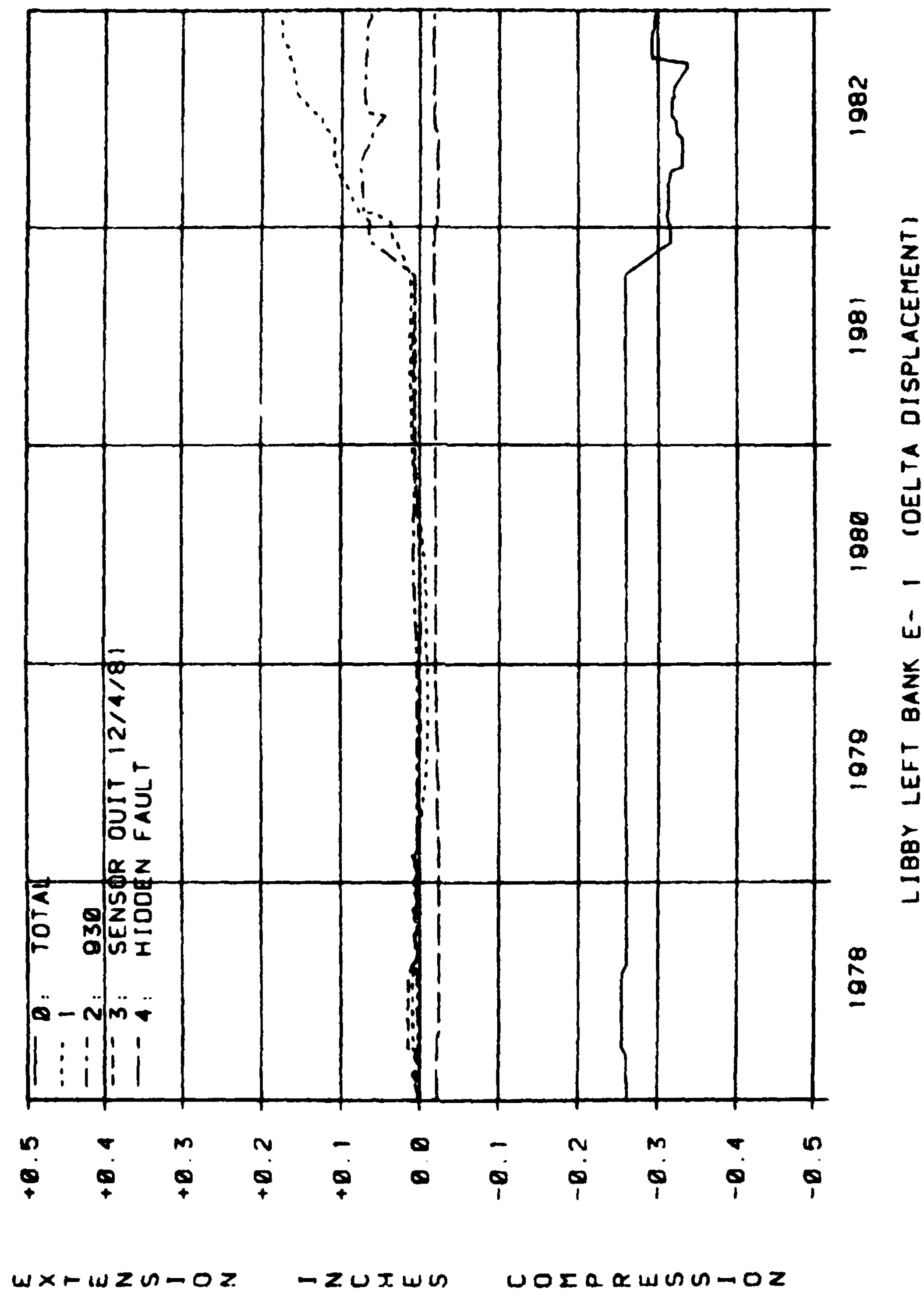

EXTENSION INCHES COMPRESSION
+0.5
+0.4
+0.3
+0.2
+0.1
0.0
-0.1
-0.2
-0.3
-0.4
-0.5
5
6
7
8
928
1968
1969
1970
1971
1972
LIBBY LEFT BANK E- 1 (DELTA DISPLACEMENT)

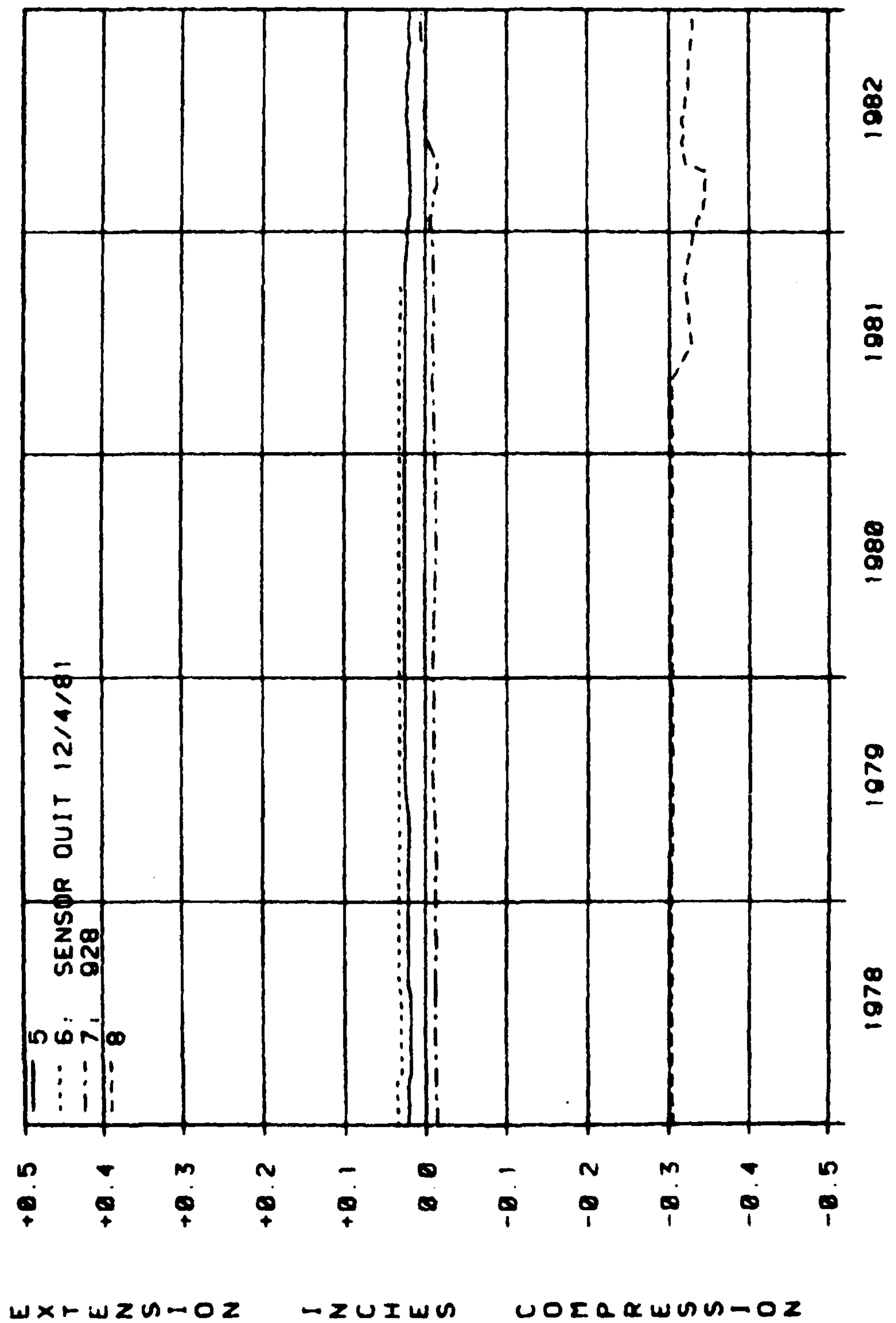


LIBBY LEFT BANK E- 1 (DELTA DISPLACEMENT)

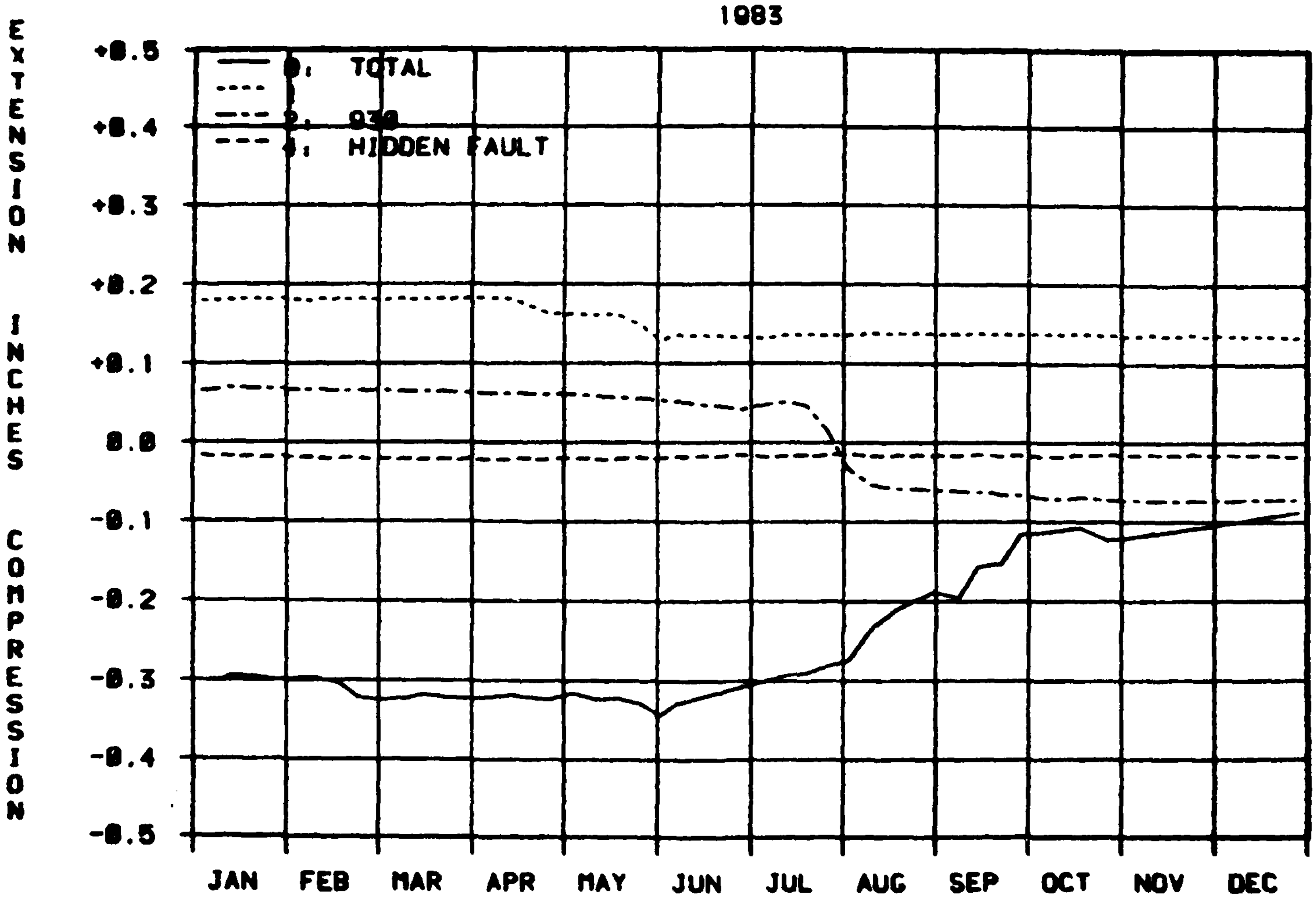


LIBBY LEFT BANK E- 1 (DELTA DISPLACEMENT)

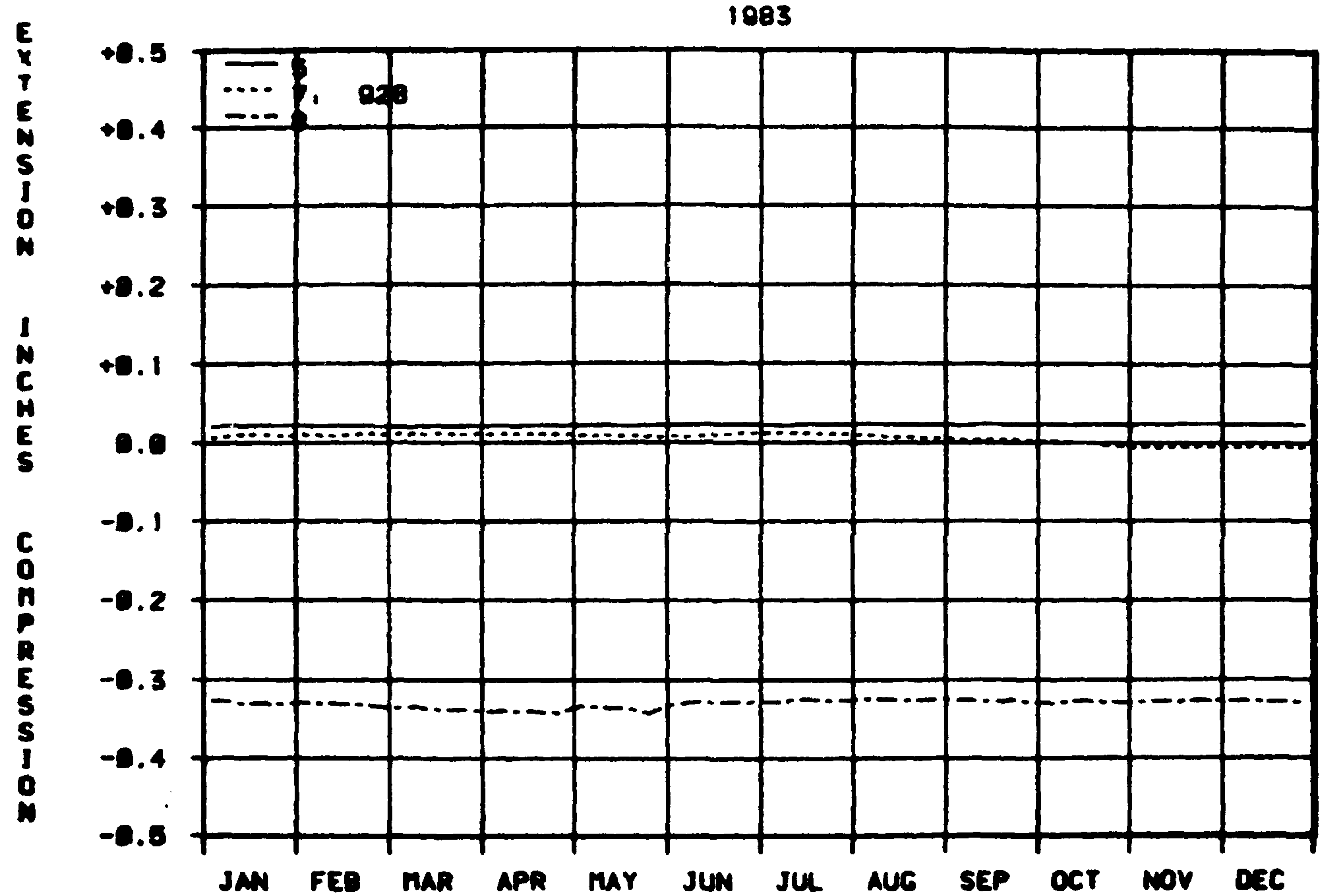

Ø: TOTAL
1
2: 930
3: SENSOR QUIT 12/4/81
4: HIDDEN FAULT
+Ø.5
+Ø.4
+Ø.3
+Ø.2
+Ø.1
Ø.Ø
-Ø.1
-Ø.2
-Ø.3
-Ø.4
-Ø.5
EXTENSION
INCHES
COMPRESSION
1978
1979
198Ø
1981
1982
LIBBY LEFT BANK E- 1 (DELTA DISPLACEMENT)



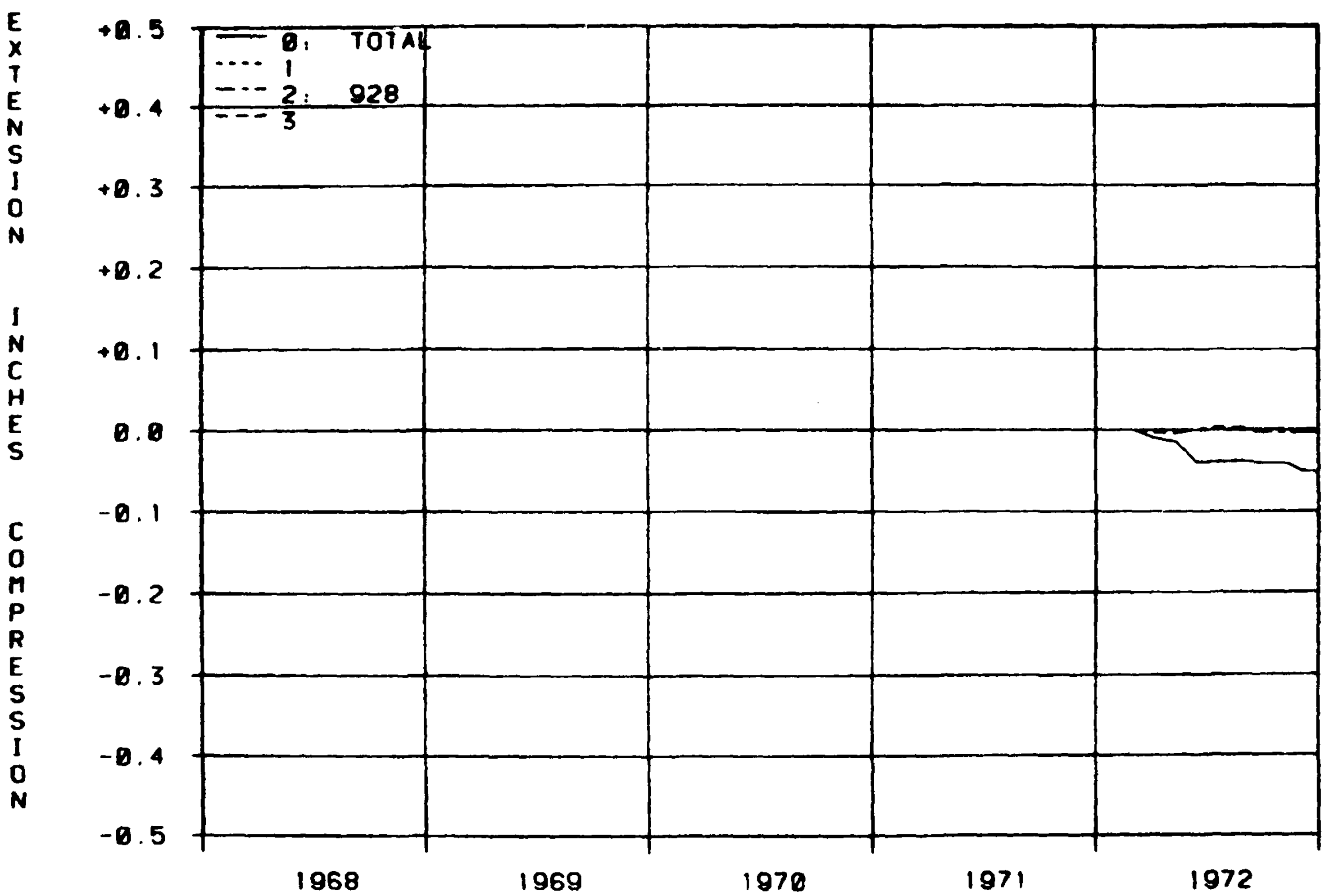
LIBBY LEFT BANK E- 1 (DELTA DISPLACEMENT)



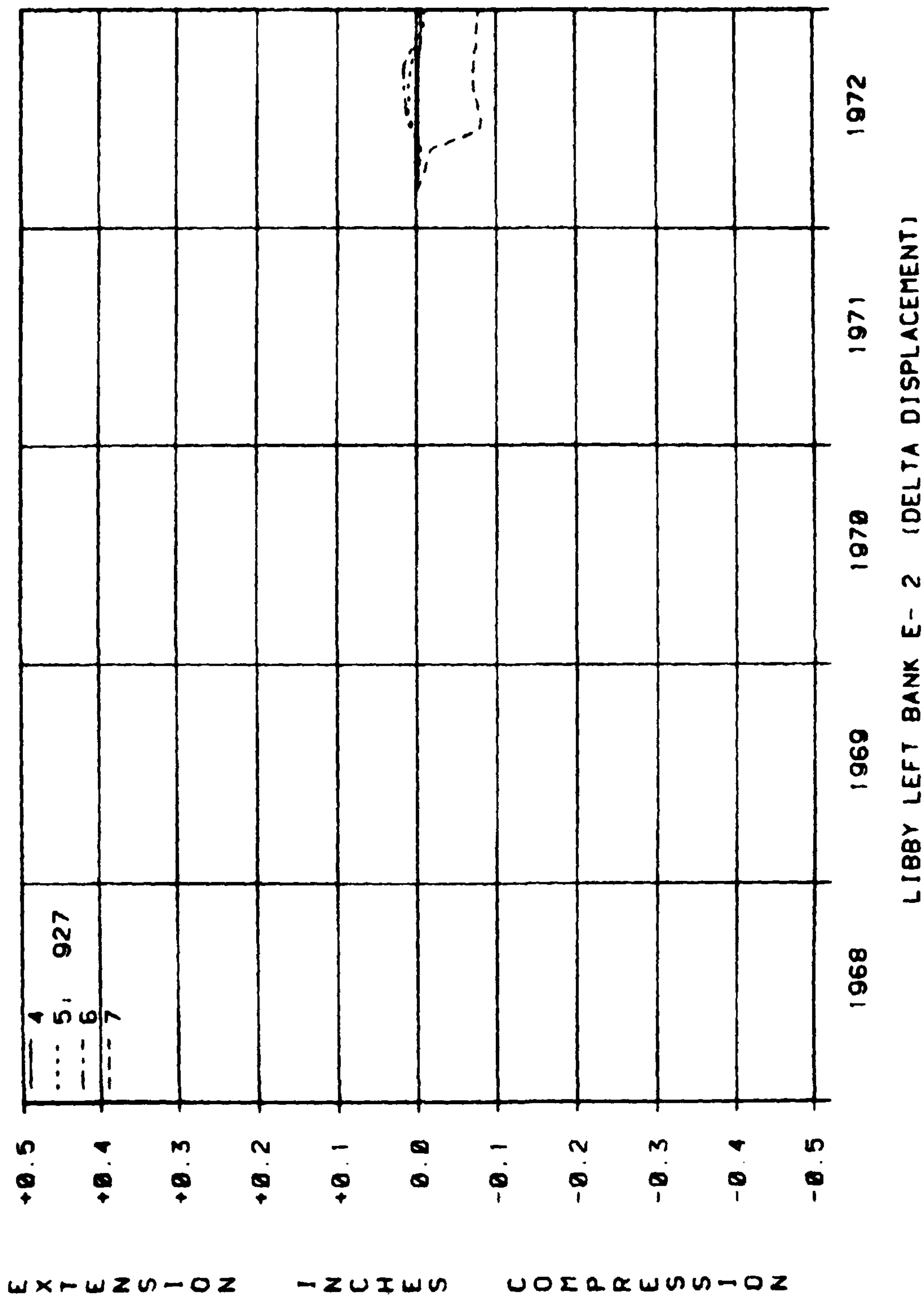
LIBBY LEFT BANK E- 1 (DELTA DISPLACEMENT)

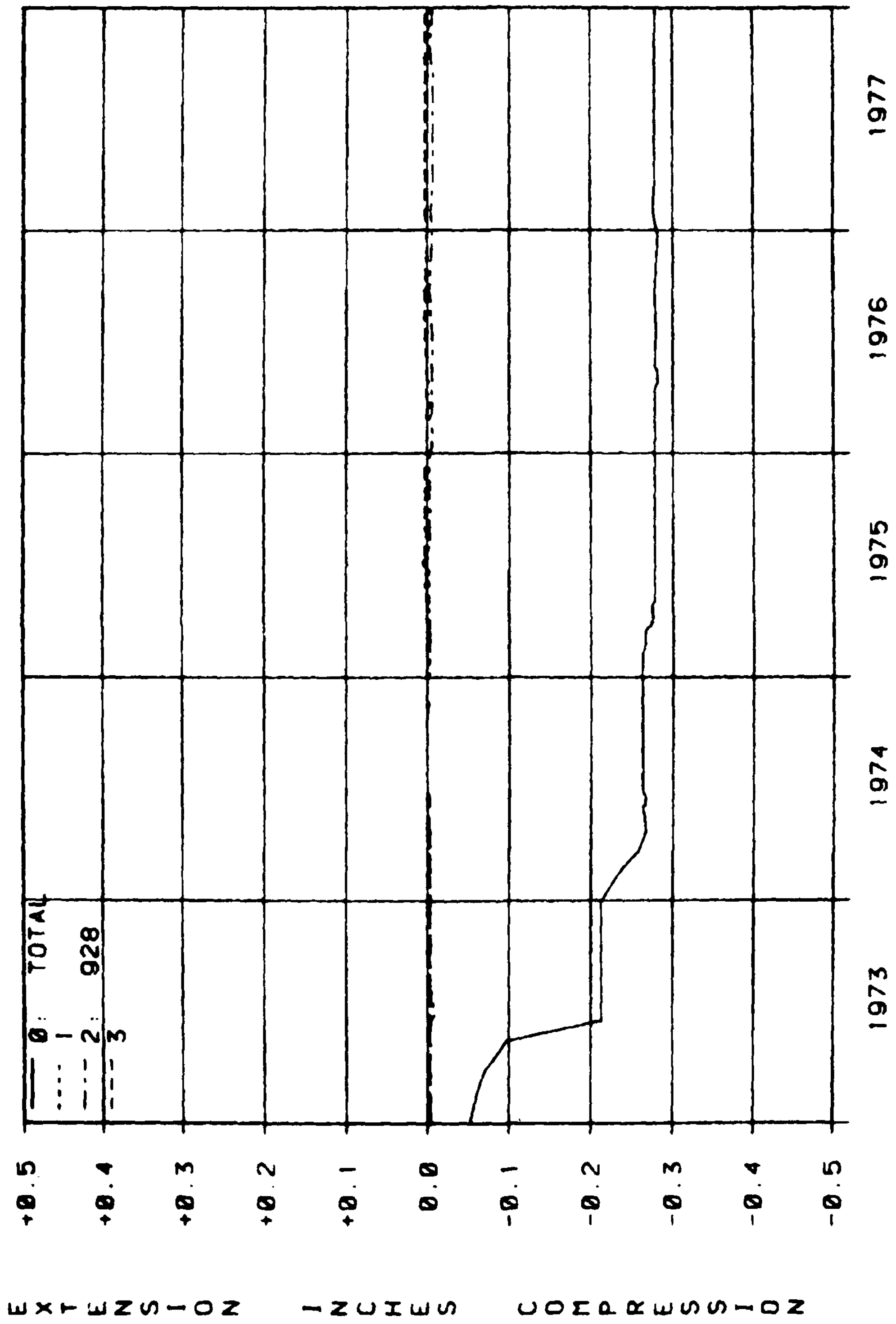


LIBBY LEFT BANK E- 1 (DELTA DISPLACEMENT)

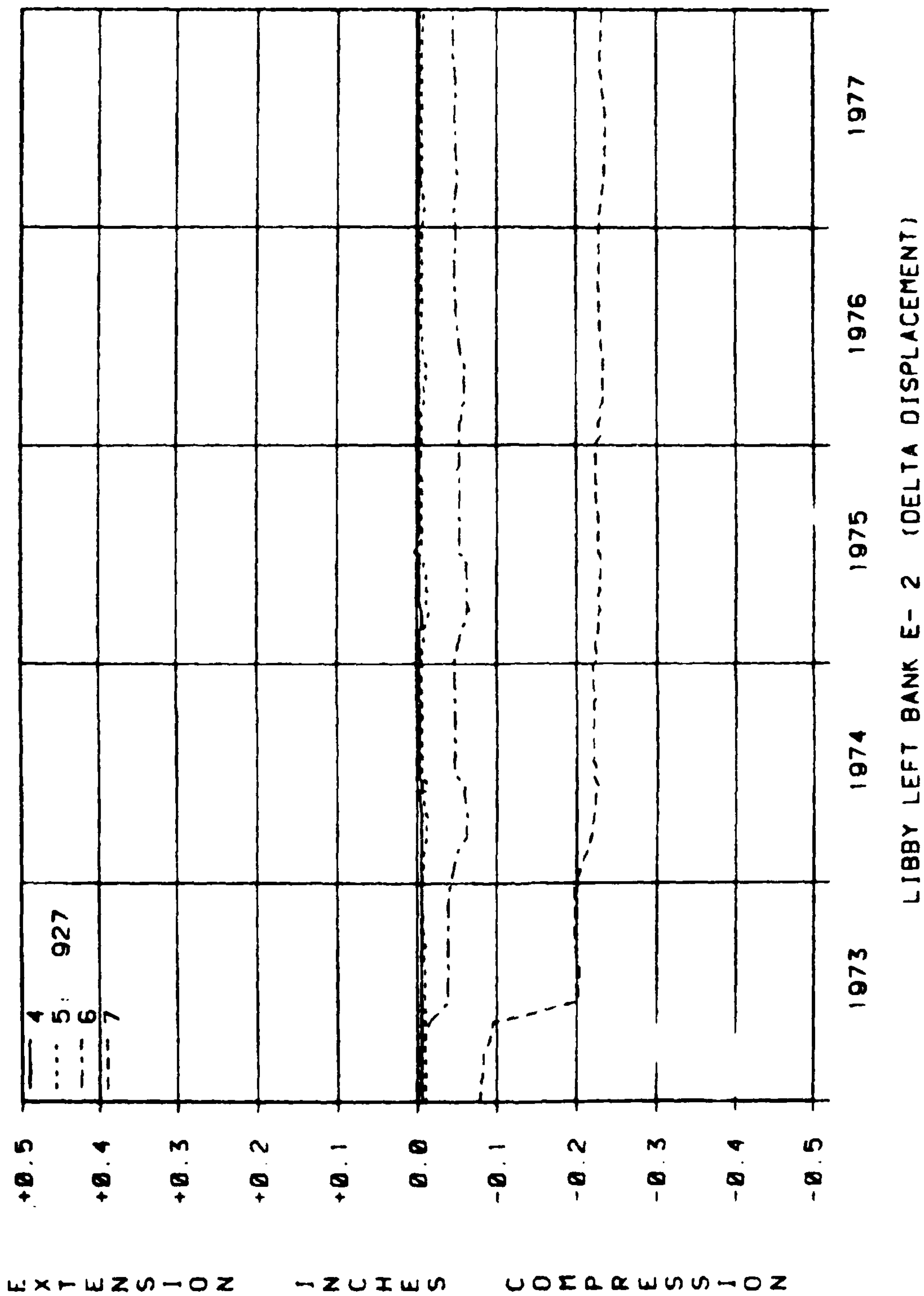


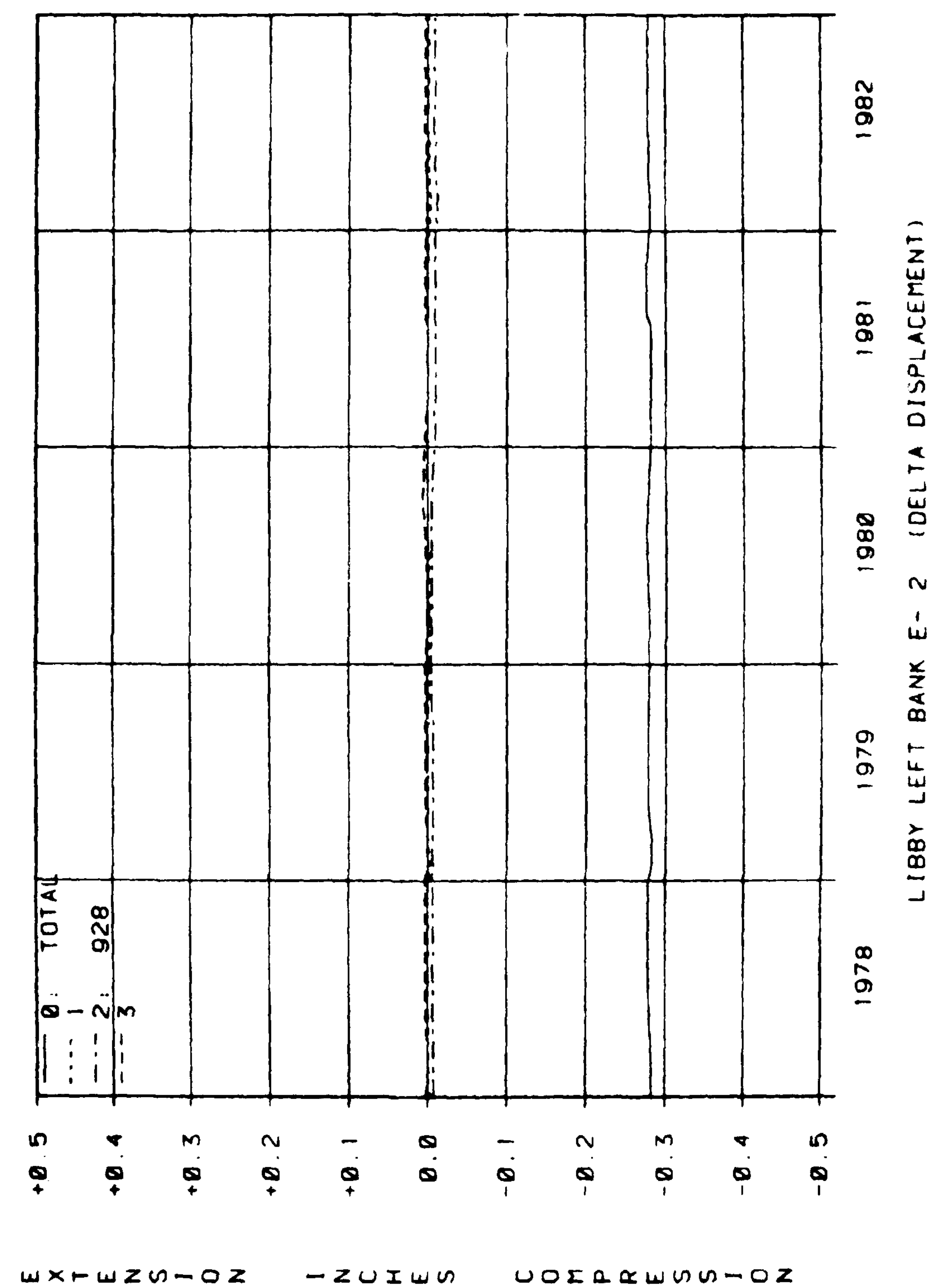
LIBBY LEFT BANK E- 2 (DELTA DISPLACEMENT)

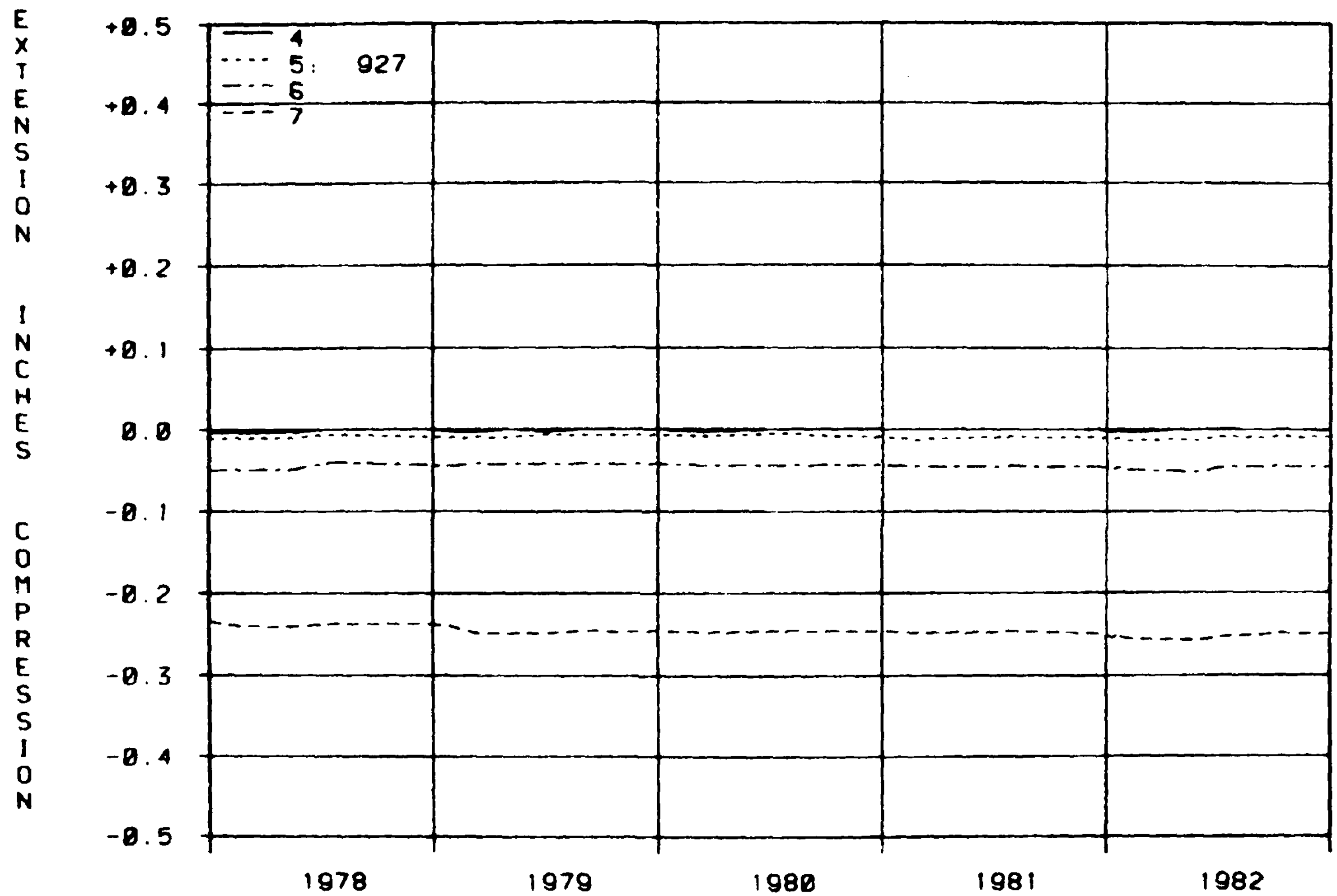

LIBBY LEFT BANK E- 2 (DELTA DISPLACEMENT)
1968
1969
1970
1971
1972
EXTENSION INCHES COMPRESSION
+0.5
+0.4
+0.3
+0.2
+0.1
0.0
-0.1
-0.2
-0.3
-0.4
-0.5
4
5, 927
6
7



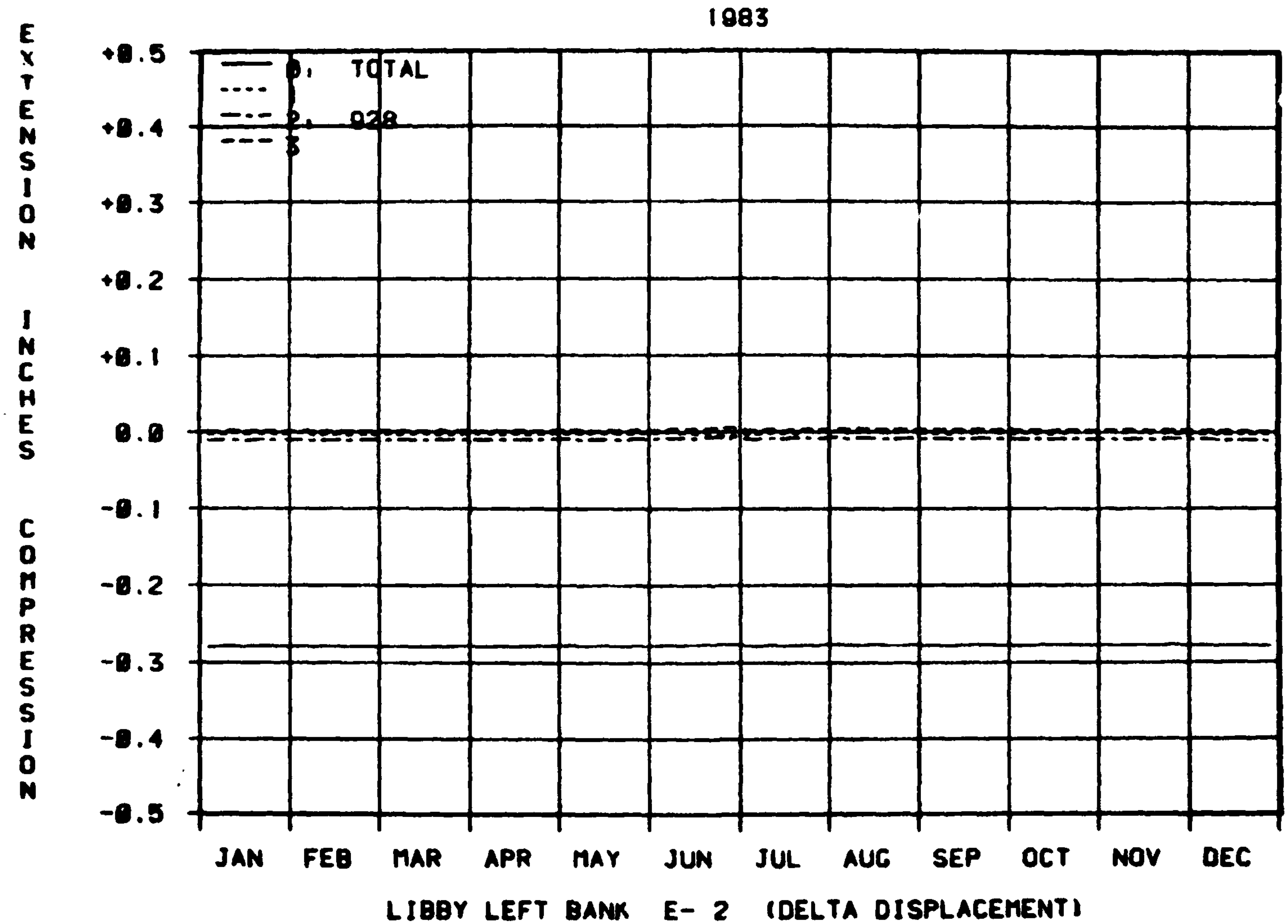
LIBBY LEFT BANK E- 2 (DELTA DISPLACEMENT)

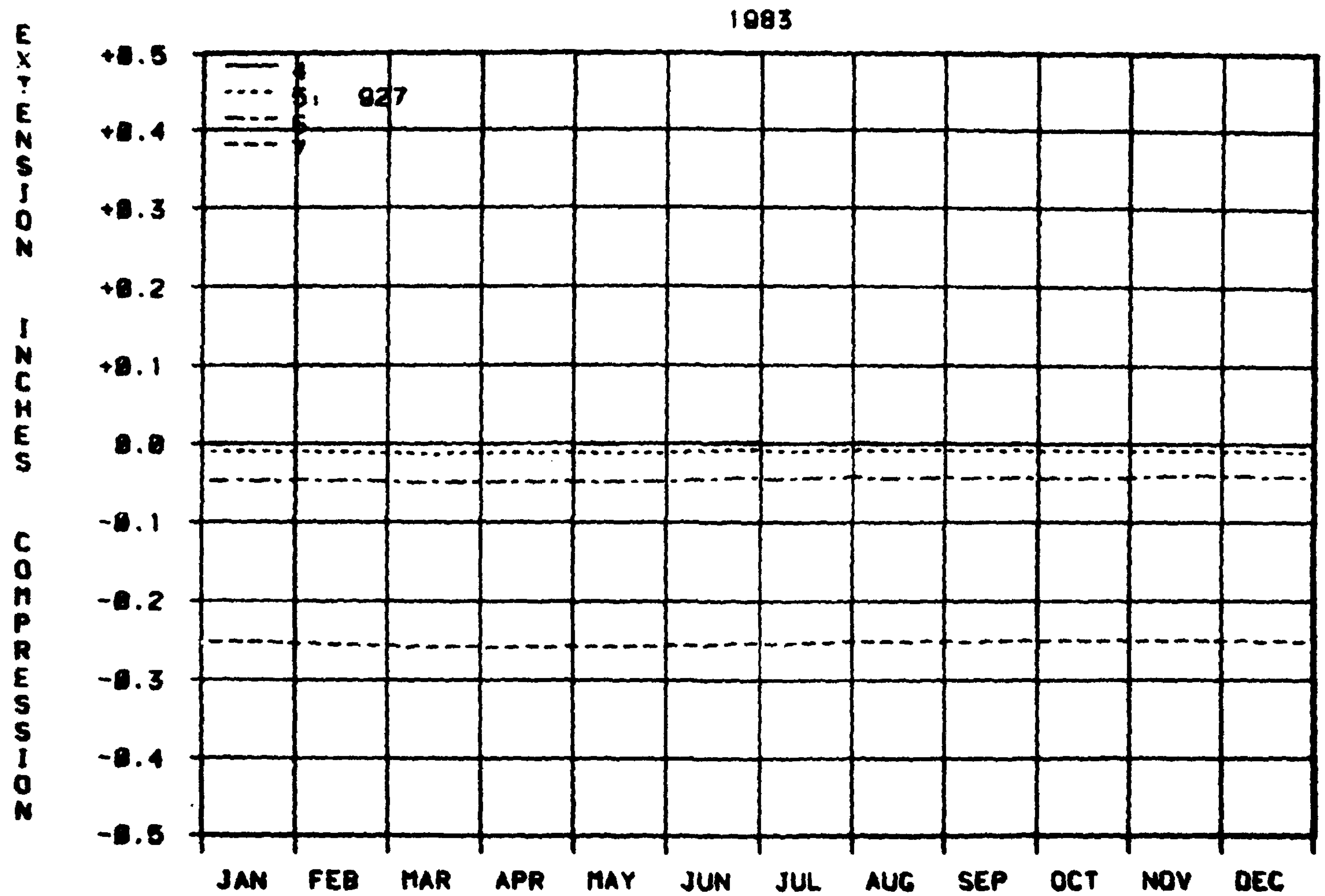

LIBBY LEFT BANK E- 2 (DELTA DISPLACEMENT)
1973
1974
1975
1976
1977
4
5
6
7
927
+0.5
+0.4
+0.3
+0.2
+0.1
0.0
-0.1
-0.2
-0.3
-0.4
-0.5
EXTENSION
INCHES
COMPRESSION


0: TOTAL
1: 928
2:
3
1978
1979
1980
1981
1982
+0.5
+0.4
+0.3
+0.2
+0.1
0.0
-0.1
-0.2
-0.3
-0.4
-0.5
EXTENSION INCHES COMPRESSION
LIBBY LEFT BANK E- 2 (DELTA DISPLACEMENT)

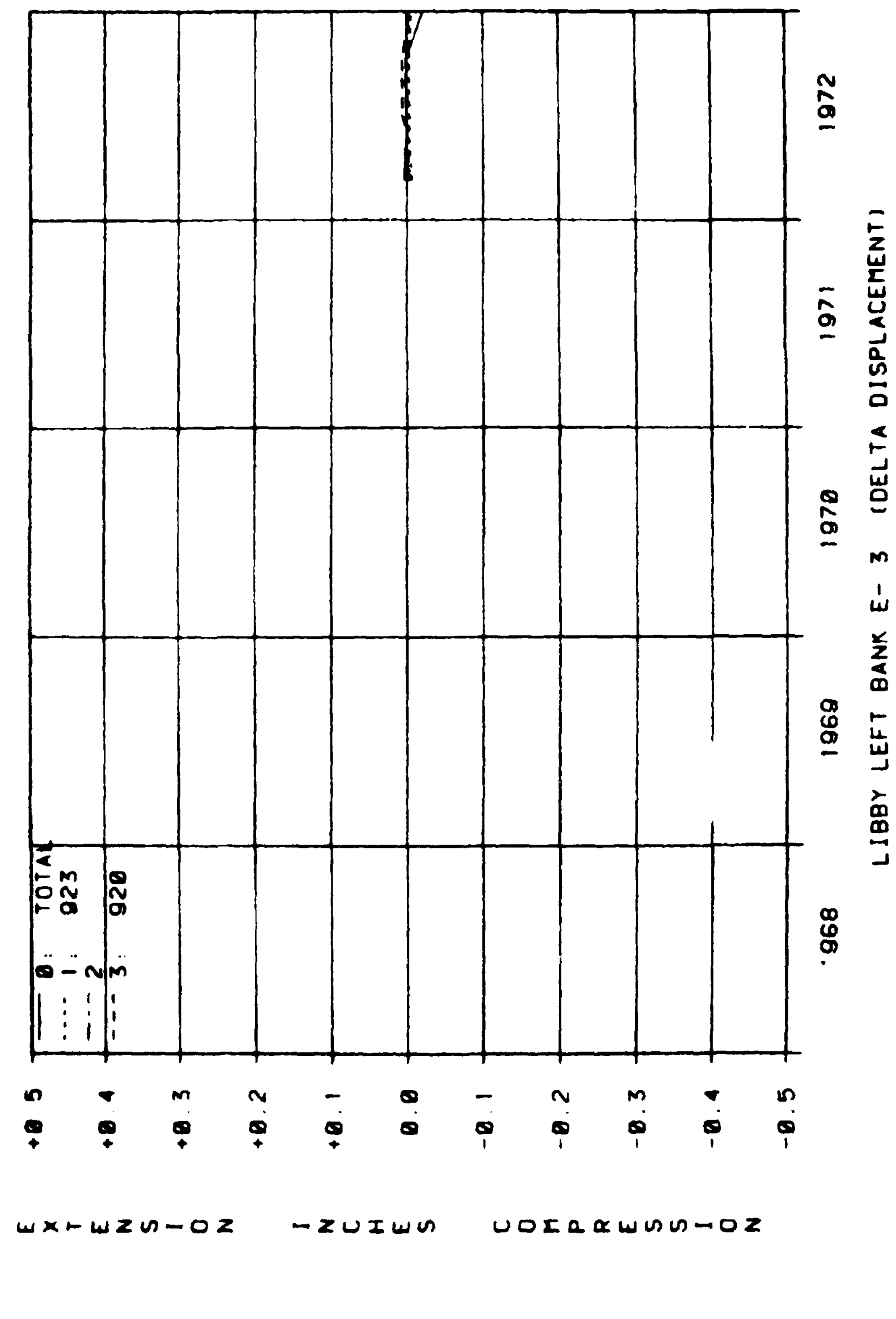


LIBBY LEFT BANK E- 2 (DELTA DISPLACEMENT)

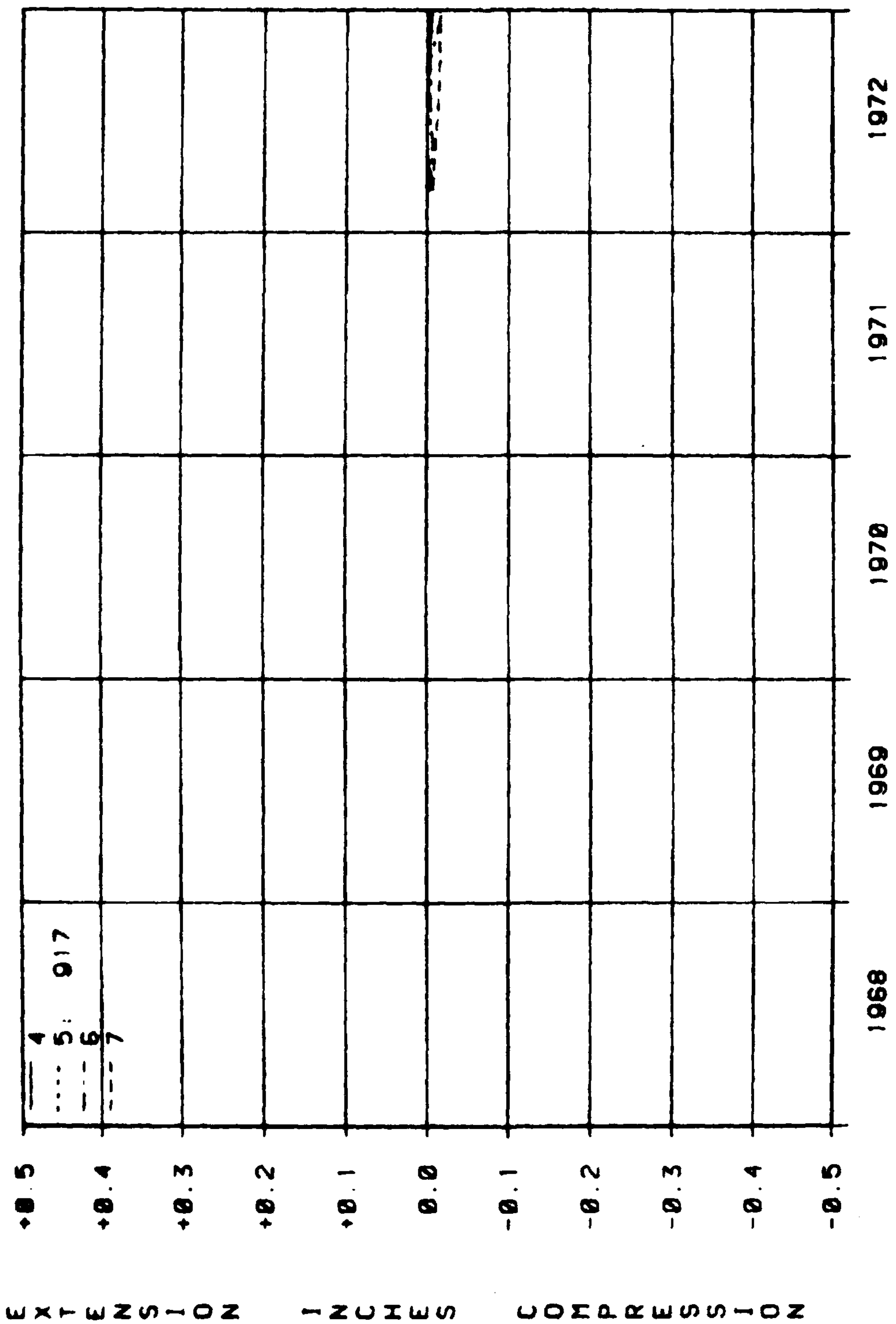

1983
EXTENSION INCHES COMPRESSION
+0.5
+0.4
+0.3
+0.2
+0.1
0.0
-0.1
-0.2
-0.3
-0.4
-0.5
0, TOTAL
1
2, 028
3
JAN FEB MAR APR MAY JUN JUL AUG SEP OCT NOV DEC
LIBBY LEFT BANK E- 2 (DELTA DISPLACEMENT)



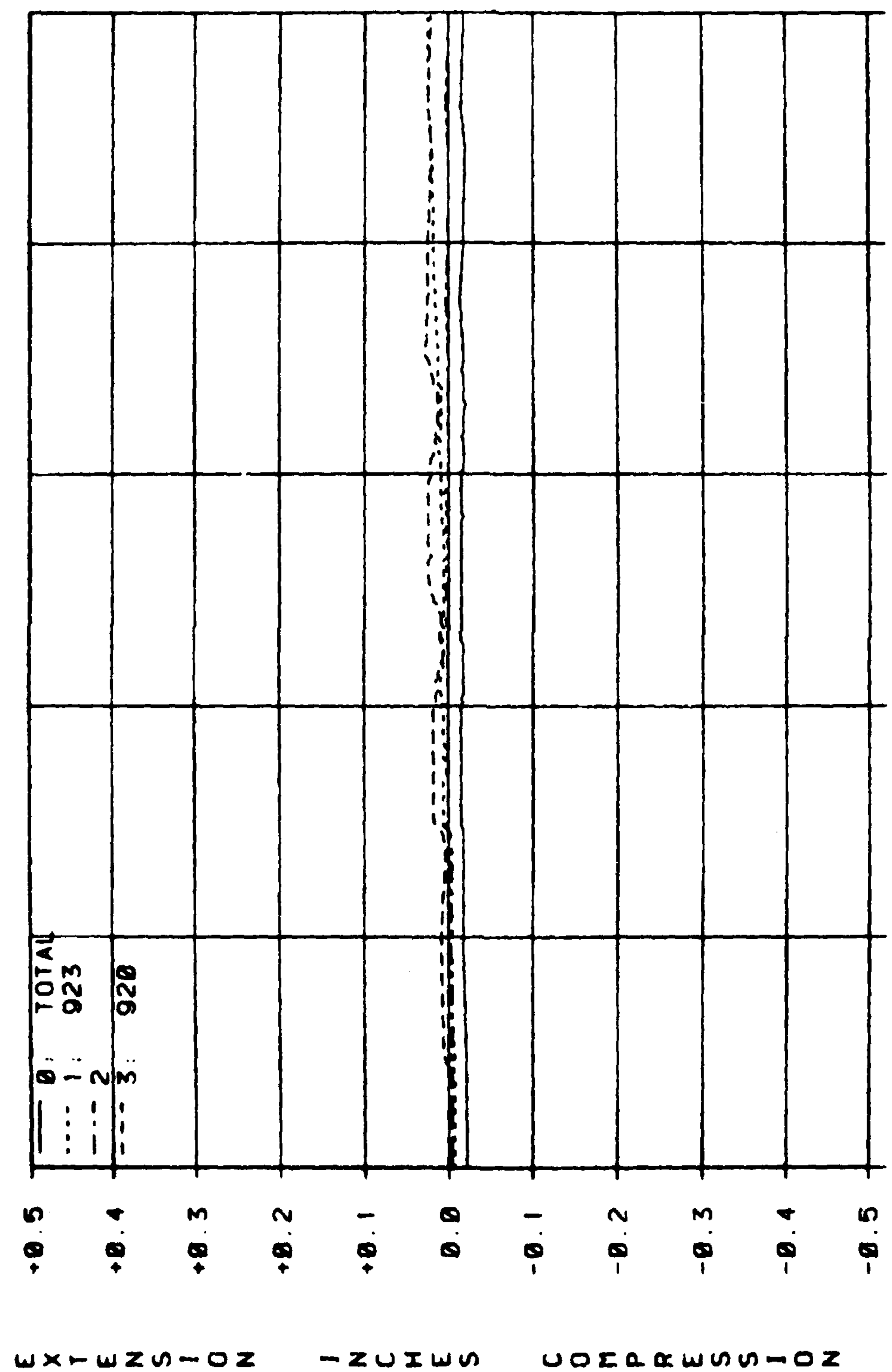
LIBBY LEFT BANK E- 2 (DELTA DISPLACEMENT)



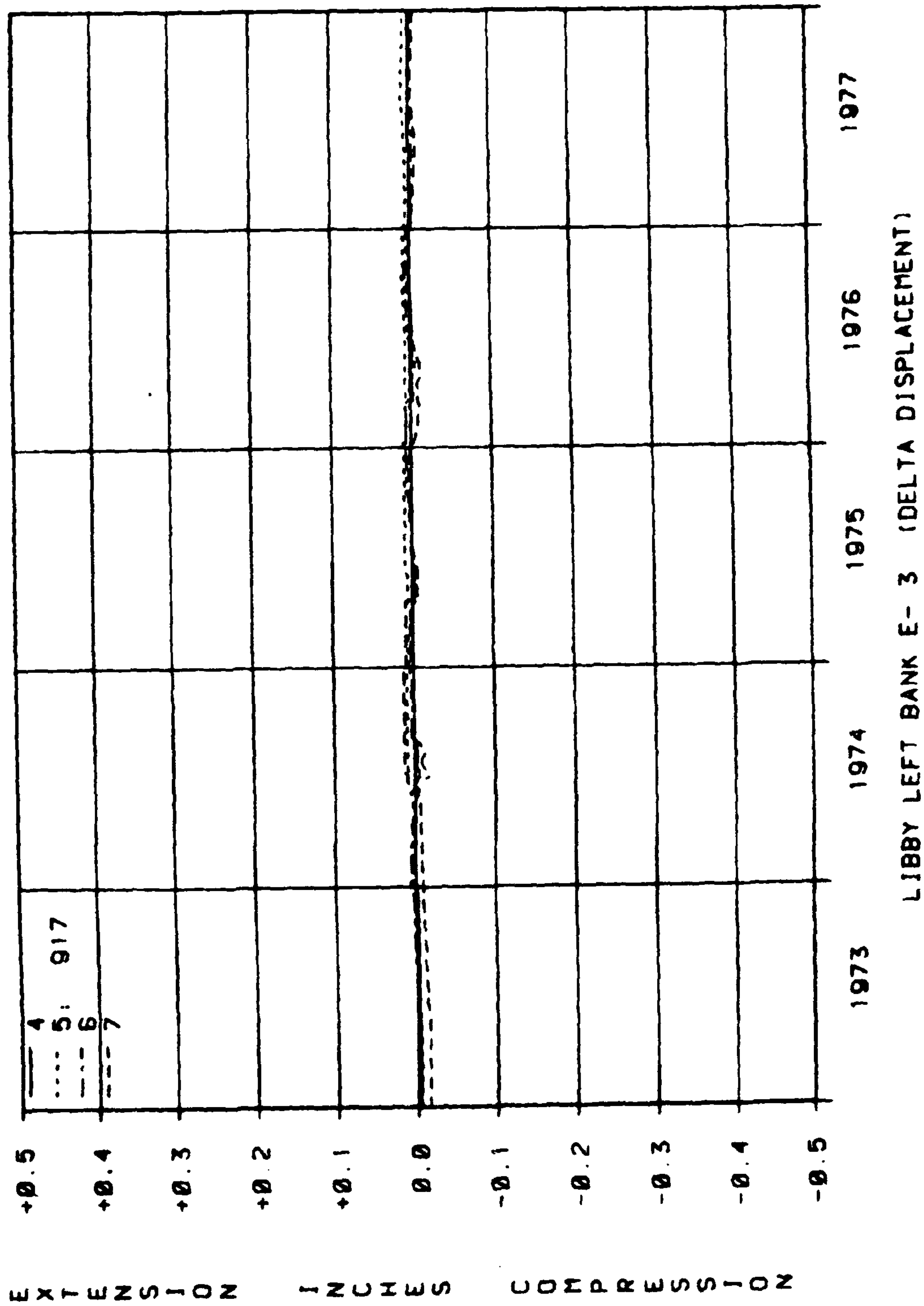
0: TOTAL
1: 923
2
3: 920
+0.5
+0.4
+0.3
+0.2
+0.1
0.0
-0.1
-0.2
-0.3
-0.4
-0.5
EXTENSION INCHES COMPRESSION
1968
1969
1970
1971
1972
LIBBY LEFT BANK E- 3 (DELTA DISPLACEMENT)



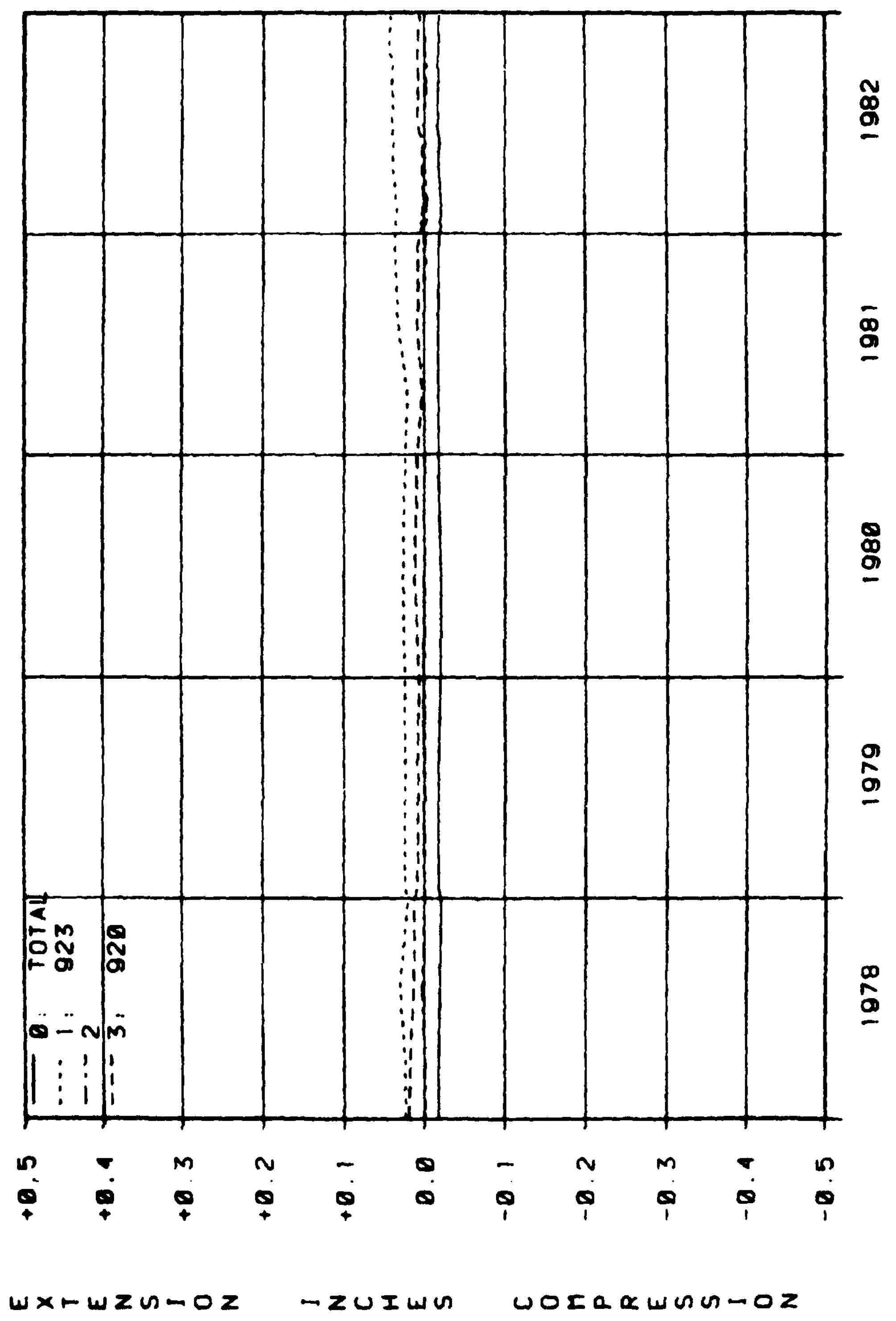
LIBBY LEFT BANK E- 3 (DELTA DISPLACEMENT)



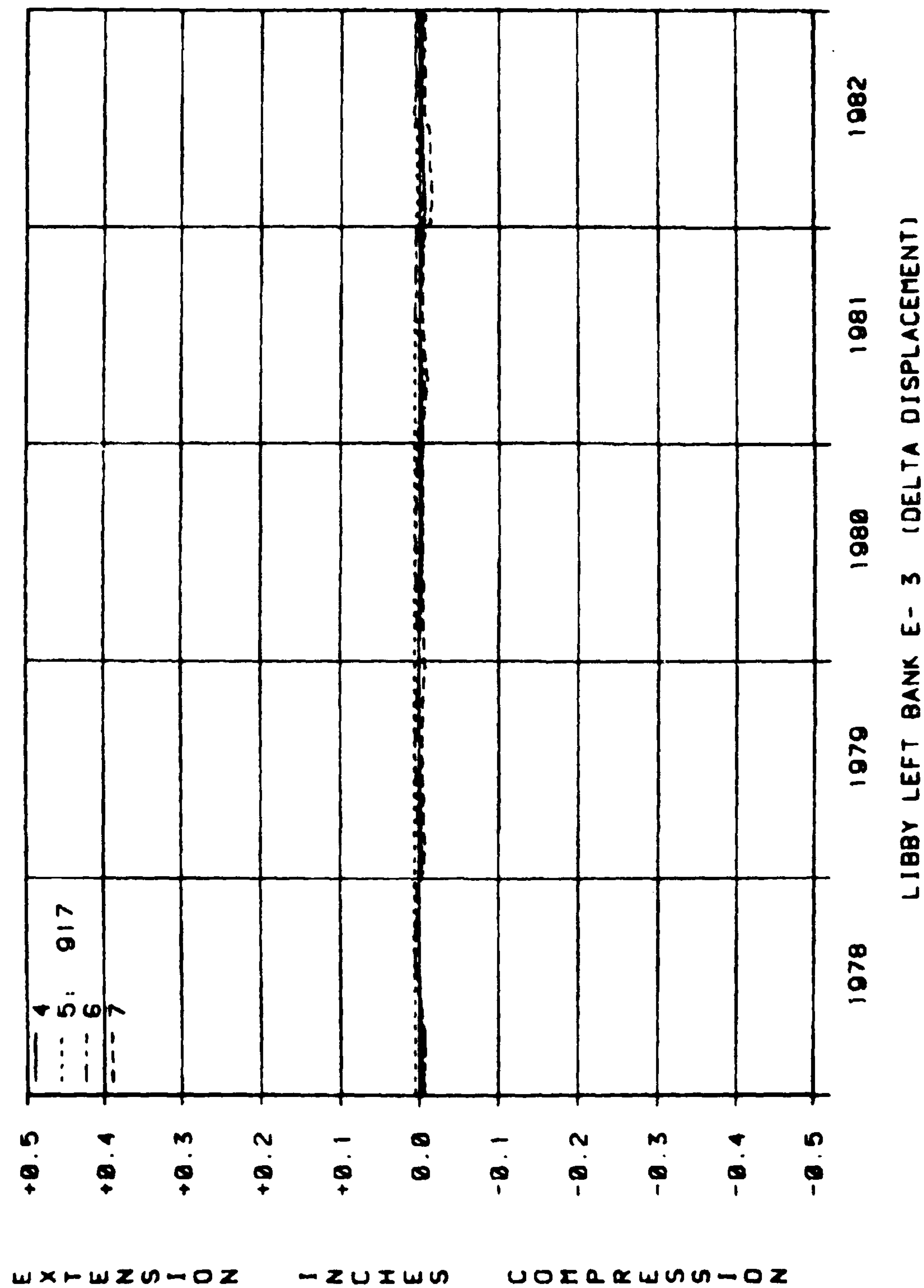
LIBBY LEFT BANK E- 3 (DELTA DISPLACEMENT)

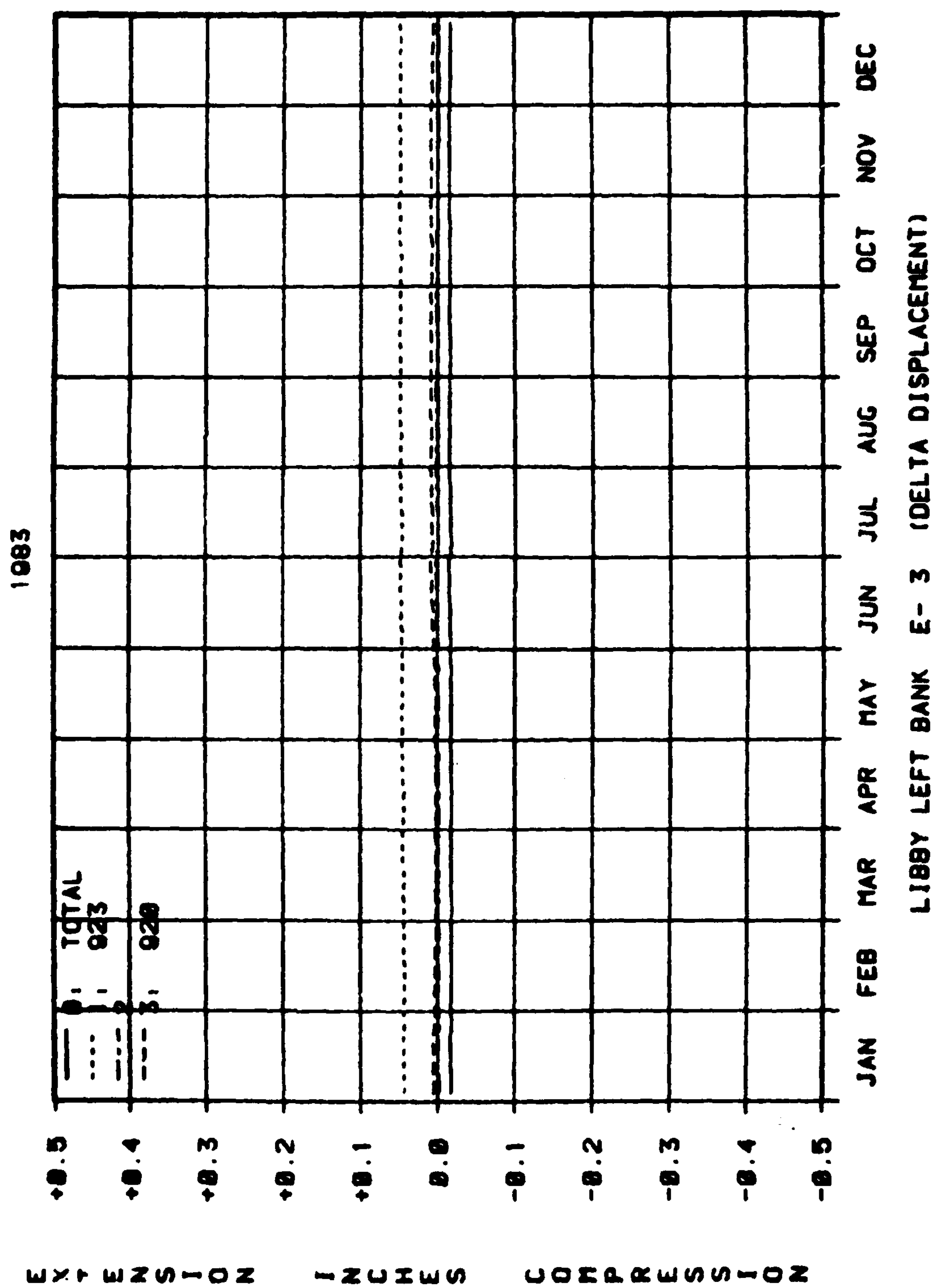


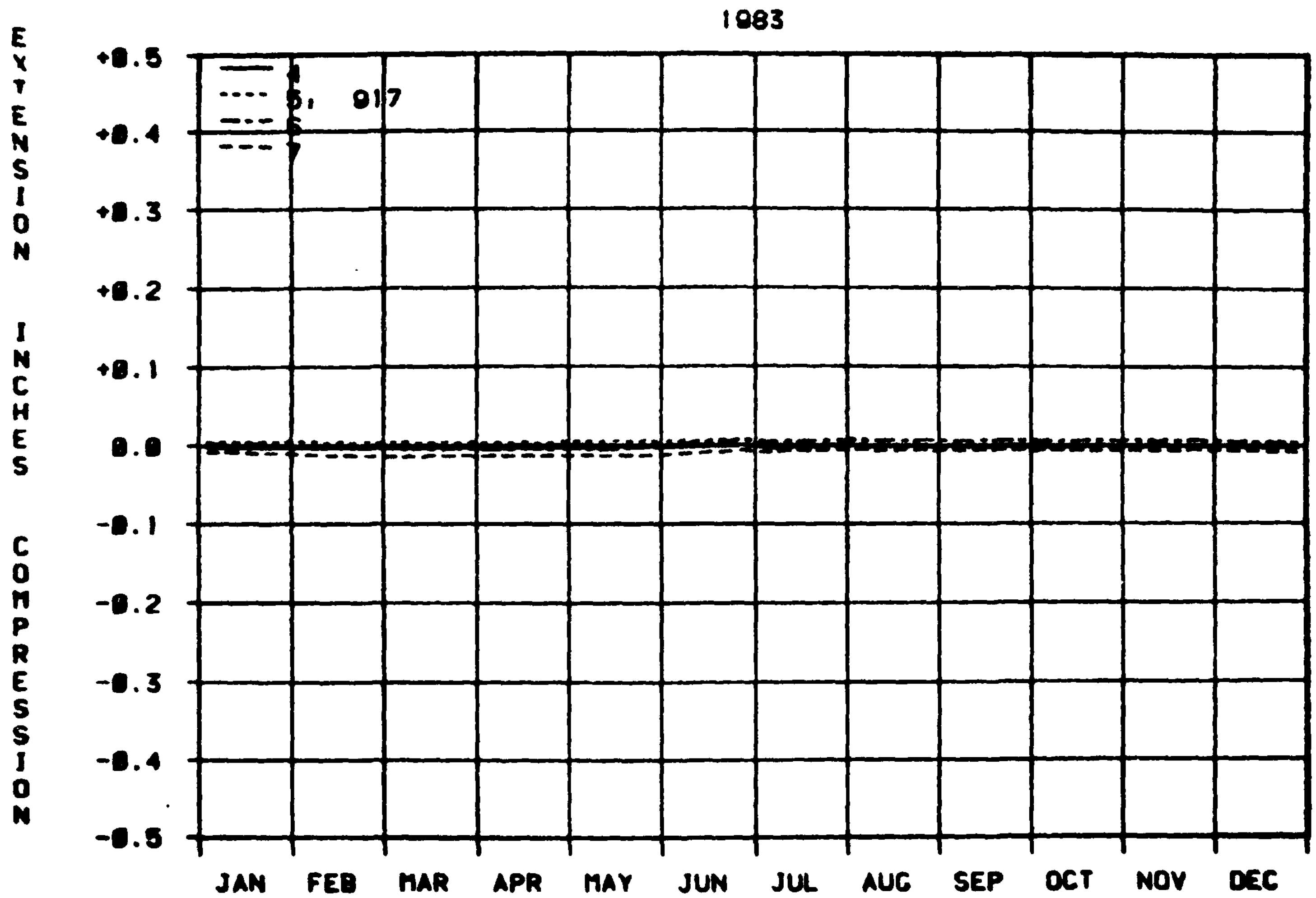
4
5: 917
6
7
+0.5
+0.4
+0.3
+0.2
+0.1
0.0
-0.1
-0.2
-0.3
-0.4
-0.5
EXTENSION INCHES COMPRESSION
1973
1974
1975
1976
1977
LIBBY LEFT BANK E- 3 (DELTA DISPLACEMENT)



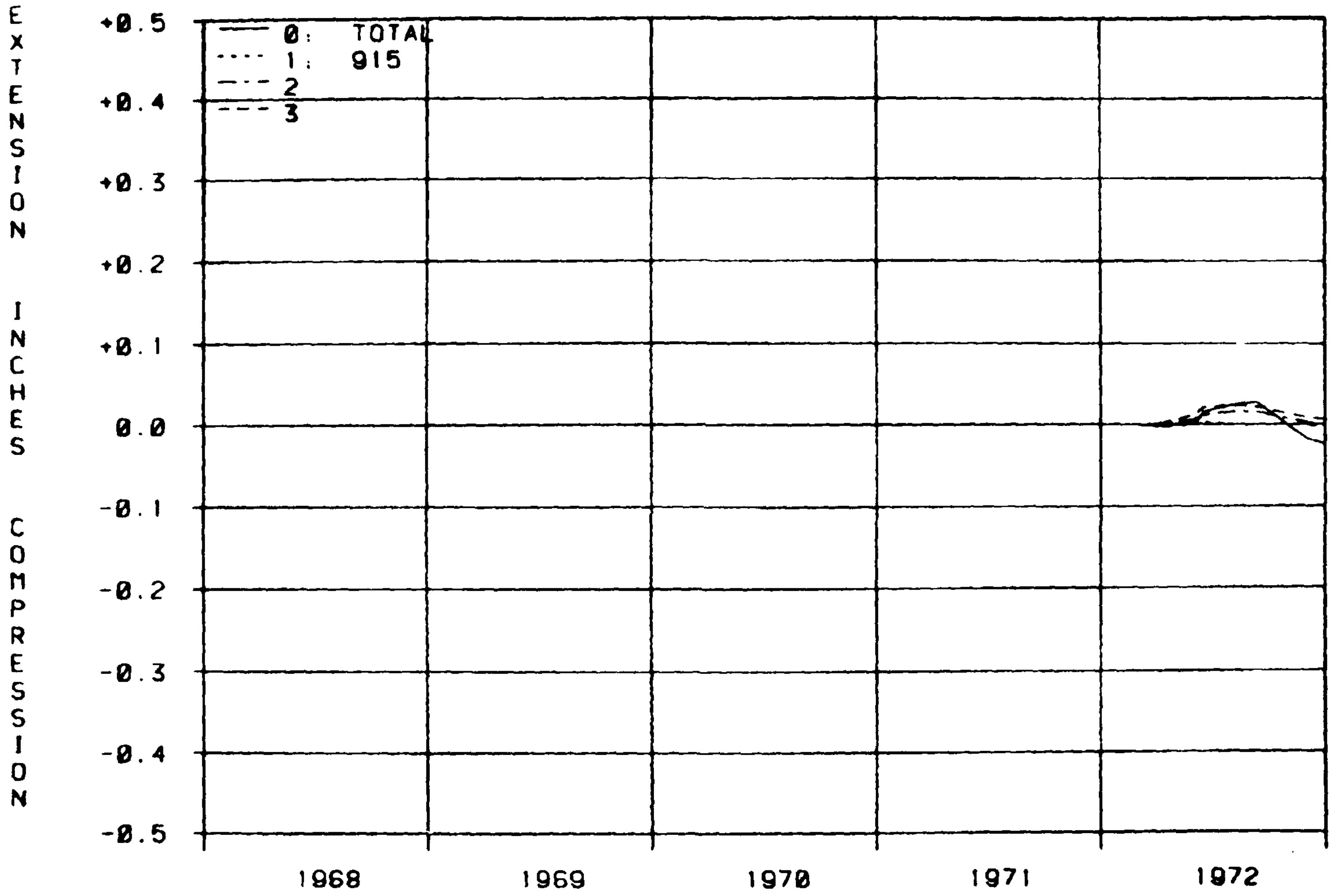
LIBBY LEFT BANK E- 3 (DELTA DISPLACEMENT)


LIBBY LEFT BANK E- 3 (DELTA DISPLACEMENT)
4
5: 917
6
7
1978
1979
1980
1981
1982
+0.5
+0.4
+0.3
+0.2
+0.1
0.0
-0.1
-0.2
-0.3
-0.4
-0.5
EXTENSION INCHES COMPRESSION

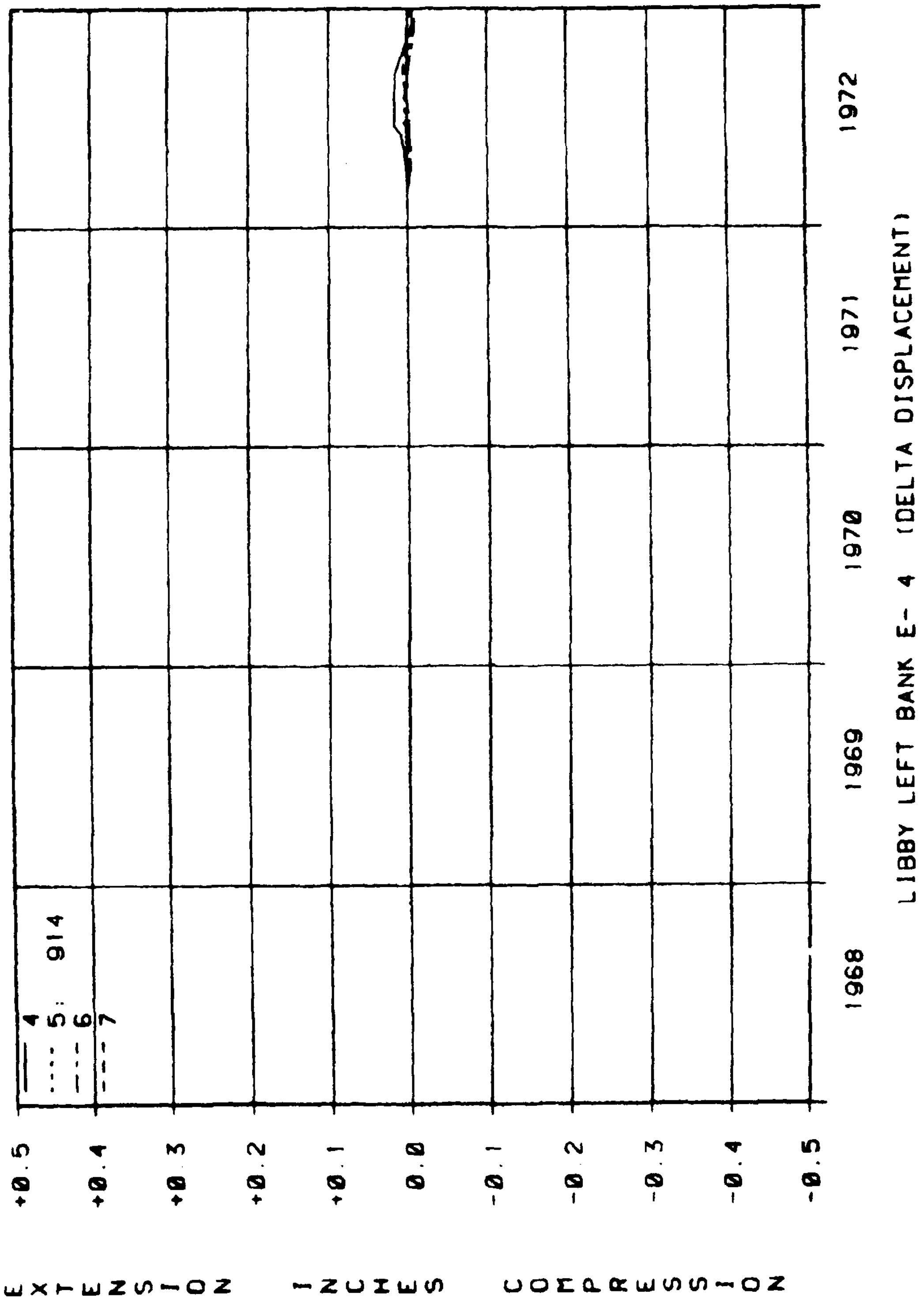

1983
TOTAL
923
928
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC
LIBBY LEFT BANK E- 3 (DELTA DISPLACEMENT)
+0.5
+0.4
+0.3
+0.2
+0.1
0.0
-0.1
-0.2
-0.3
-0.4
-0.5
EXTENSION INCHES COMPRESSION

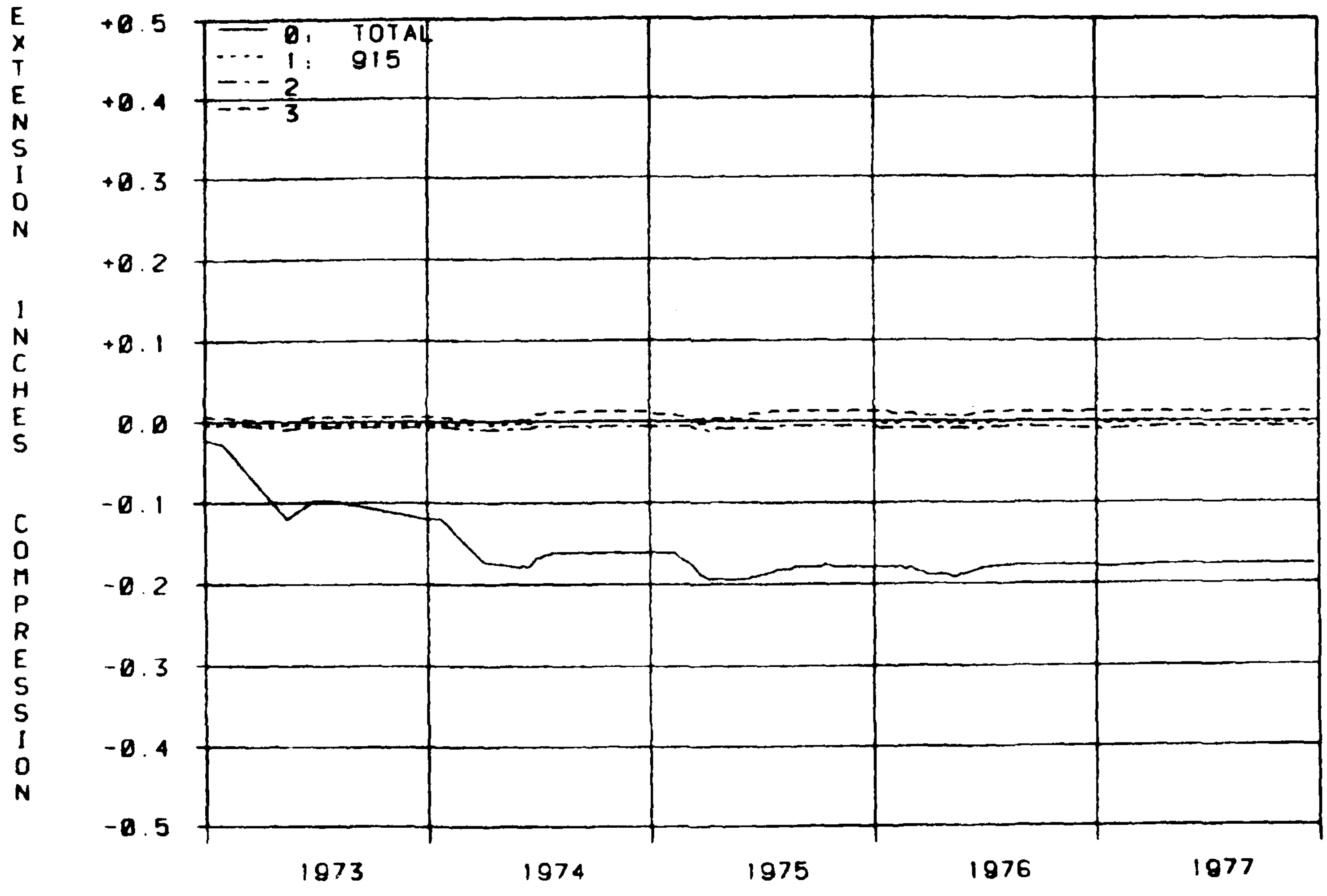


LIBBY LEFT BANK E- 3 (DELTA DISPLACEMENT)

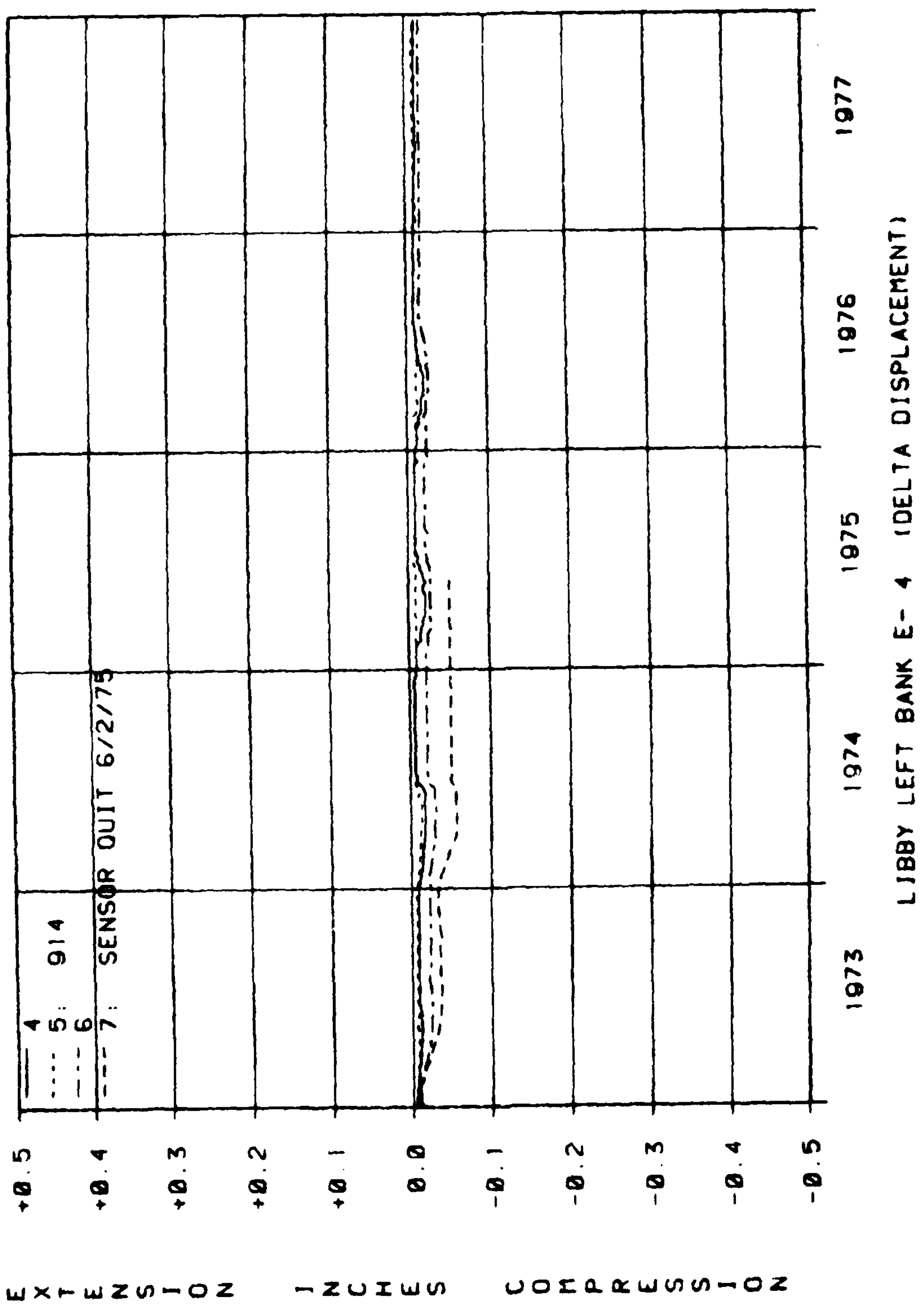


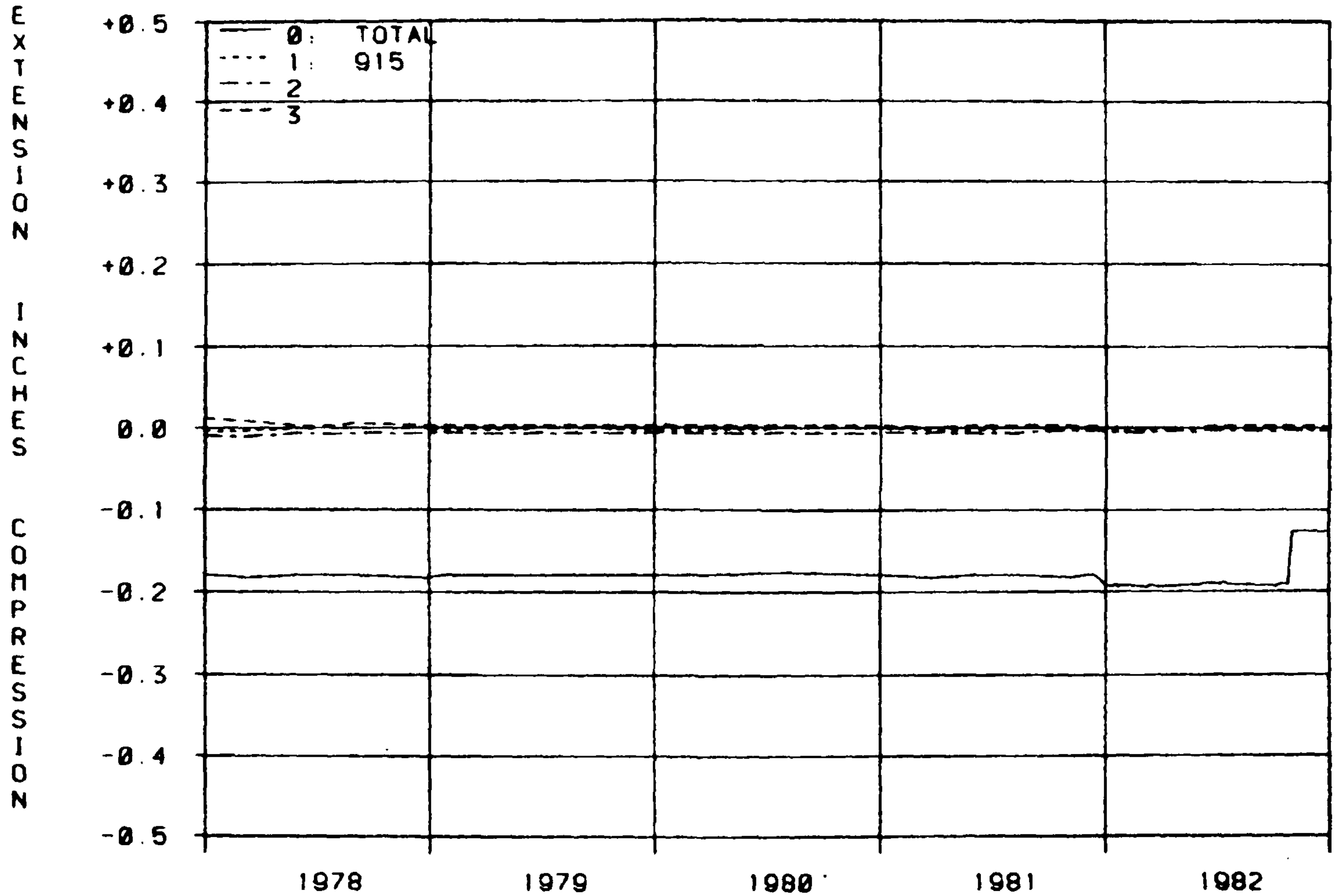
LIBBY LEFT BANK E- 4 (DELTA DISPLACEMENT)


LIBBY LEFT BANK E- 4 (DELTA DISPLACEMENT)
4
5: 914
6
7
1968
1969
1970
1971
1972
+0.5
+0.4
+0.3
+0.2
+0.1
0.0
-0.1
-0.2
-0.3
-0.4
-0.5
EXTENSION INCHES COMPRESSION

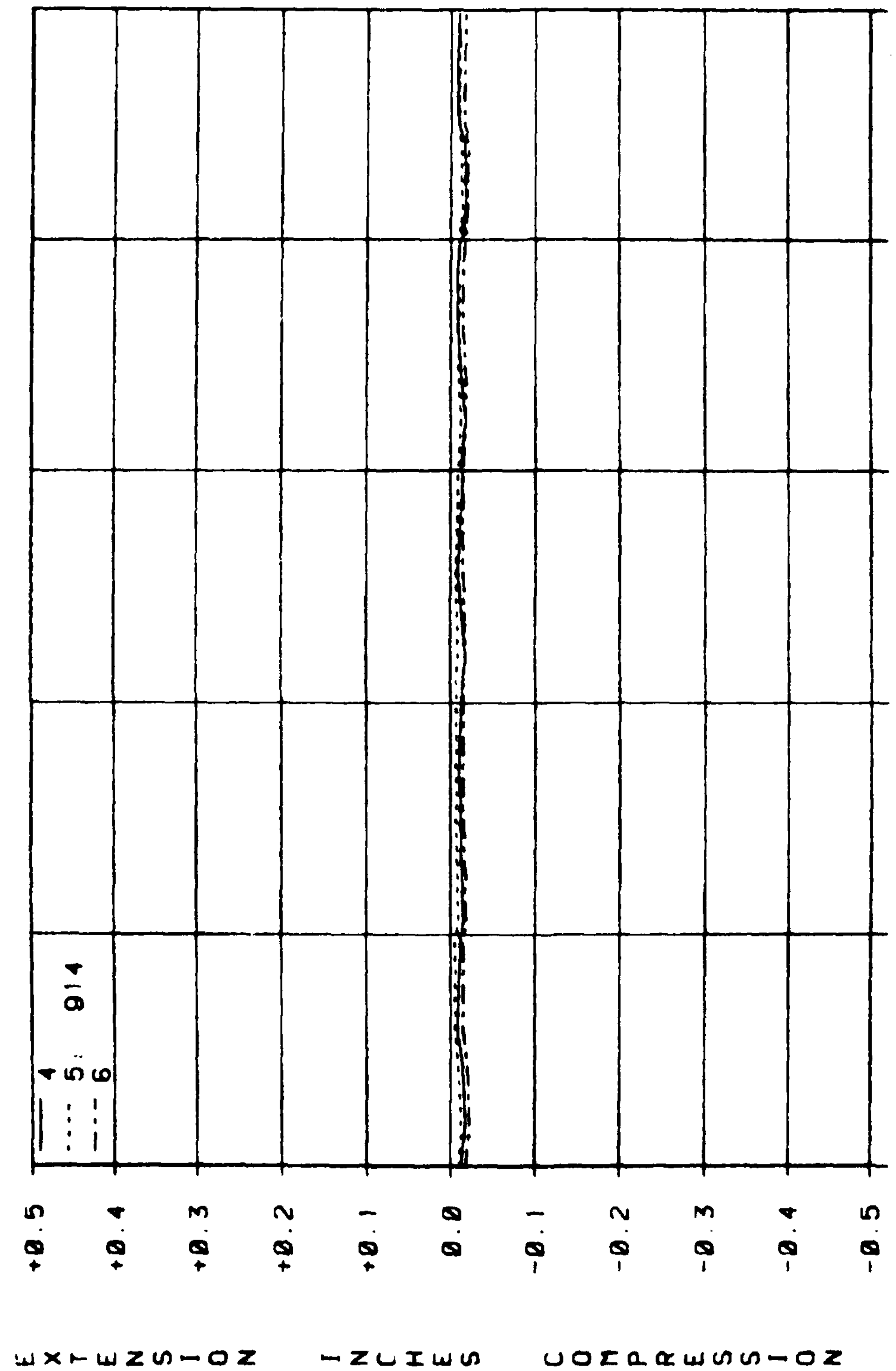


LIBBY LEFT BANK E- 4 (DELTA DISPLACEMENT)

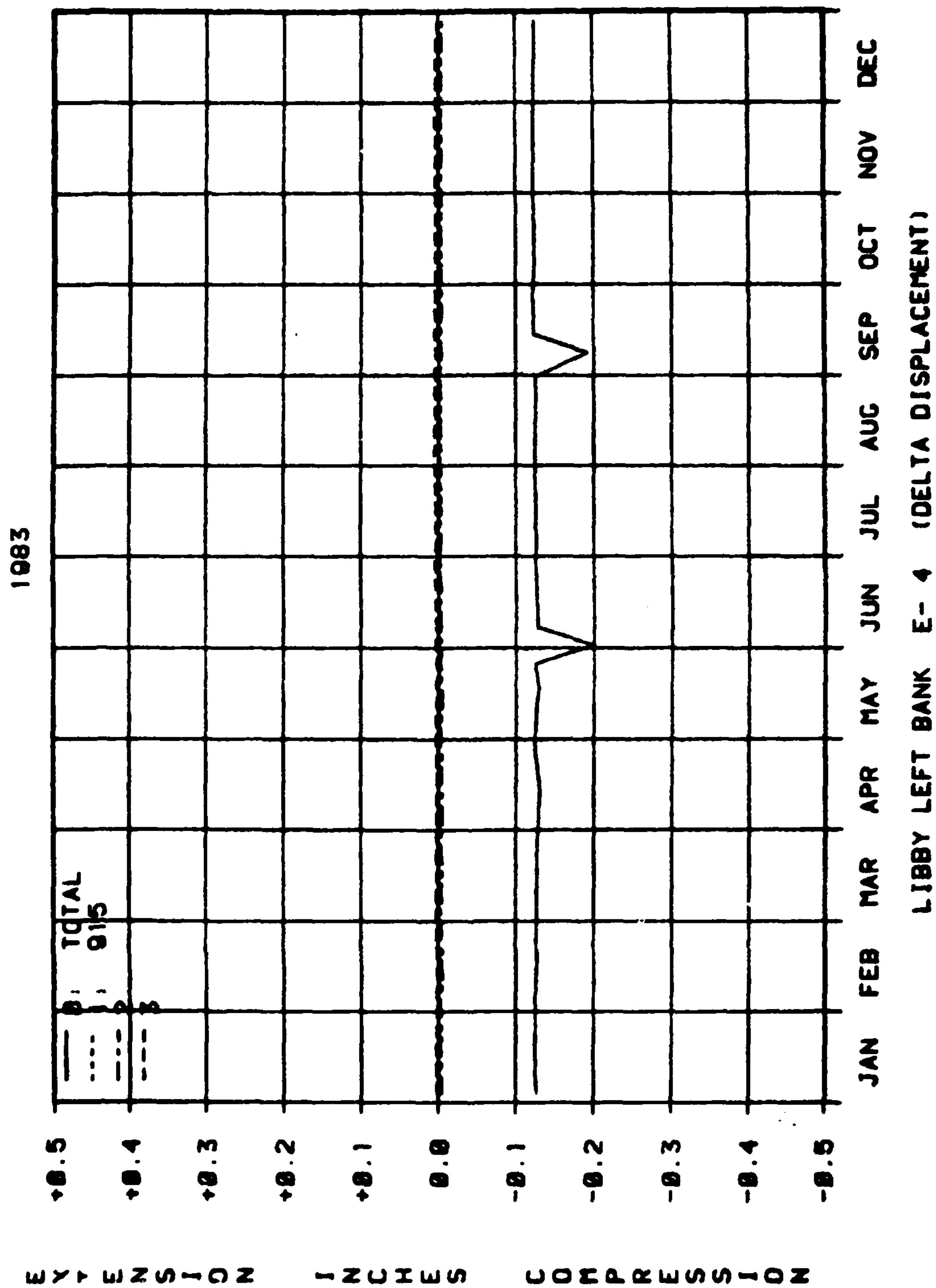

LIBBY LEFT BANK E- 4 (DELTA DISPLACEMENT)
4
5: 914
6
7: SENSOR QUIT 6/2/75
1973
1974
1975
1976
1977
+0.5
+0.4
+0.3
+0.2
+0.1
0.0
-0.1
-0.2
-0.3
-0.4
-0.5
EXTENSION INCHES COMPRESSION

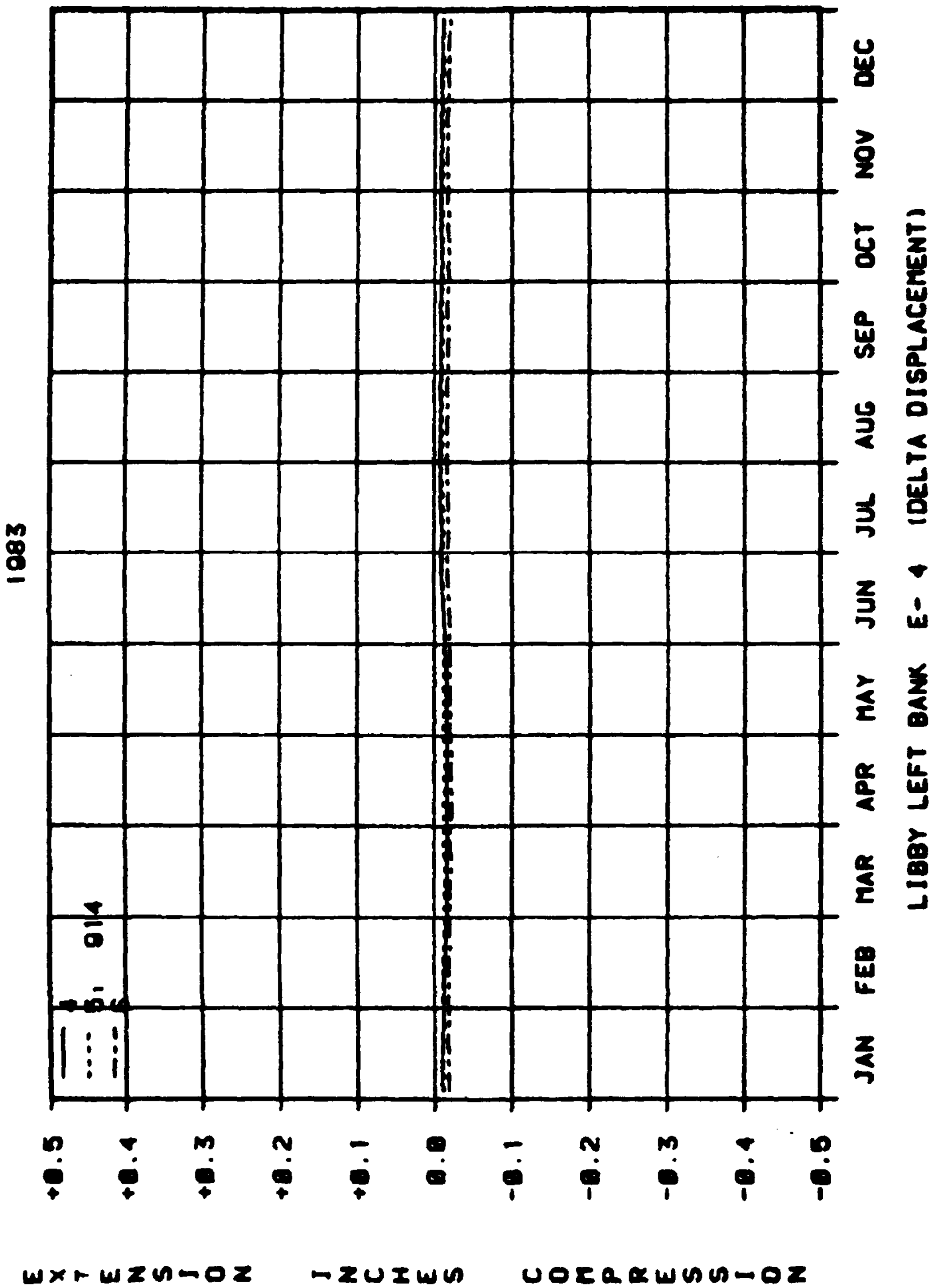


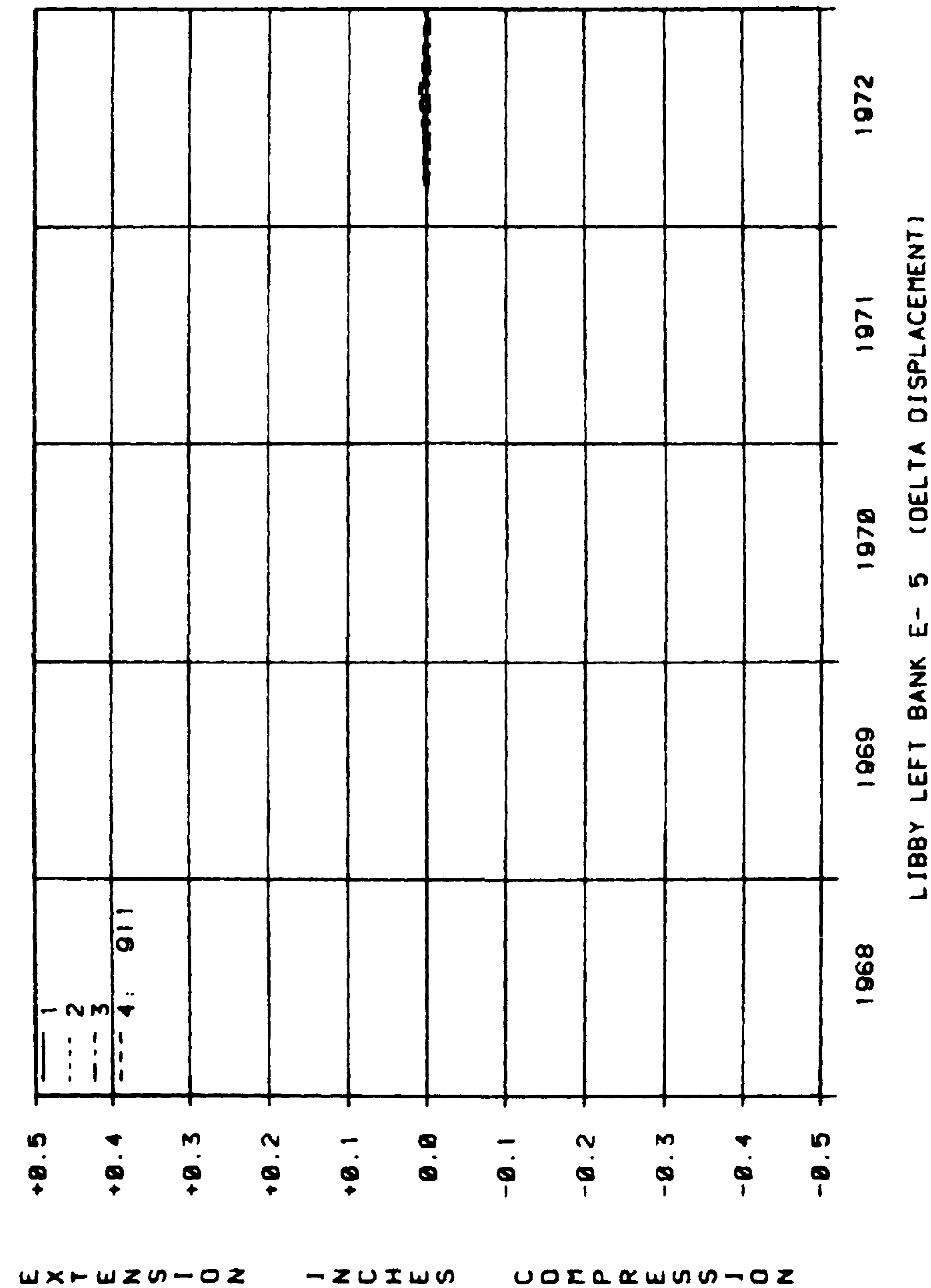
LIBBY LEFT BANK E- 4 (DELTA DISPLACEMENT)

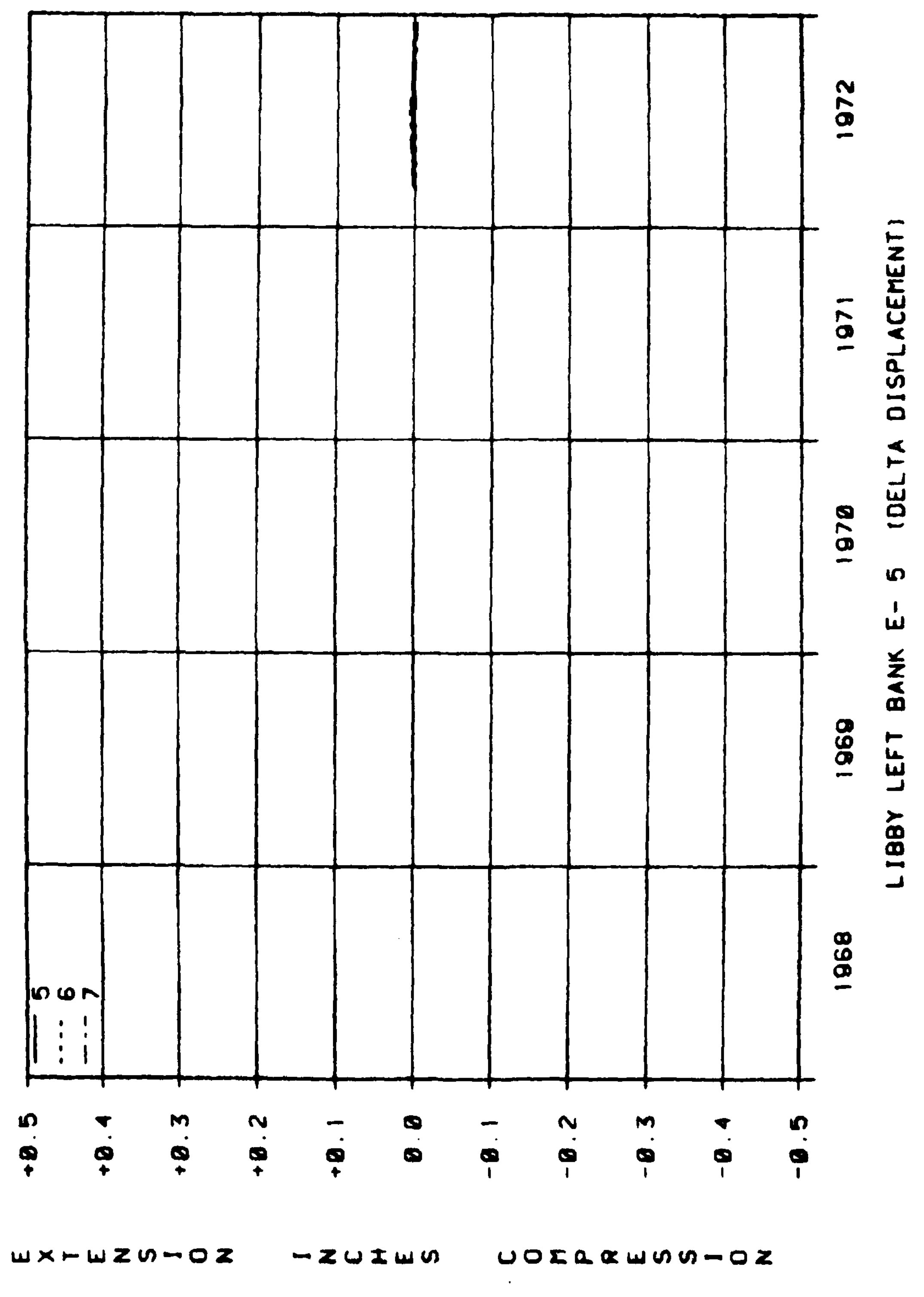


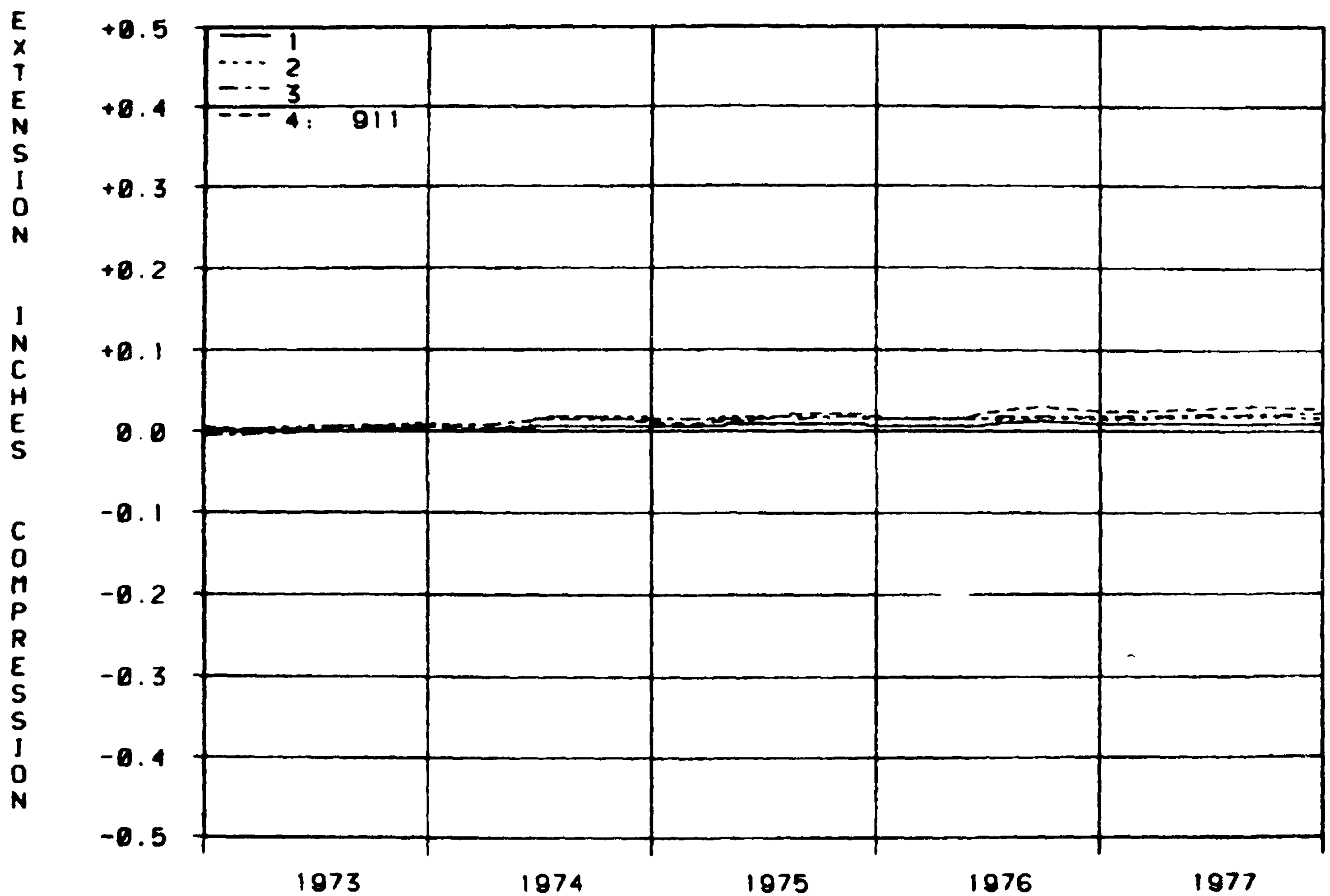
LIBBY LEFT BANK E- 4 (DELTA DISPLACEMENT)


1983
LIBBY LEFT BANK E- 4 (DELTA DISPLACEMENT)
JAN FEB MAR APR MAY JUN JUL AUG SEP OCT NOV DEC
+0.5 +0.4 +0.3 +0.2 +0.1 0.0 -0.1 -0.2 -0.3 -0.4 -0.5
EXTENSION INCHES COMPRESSION
0
1
2
3
TOTAL
915

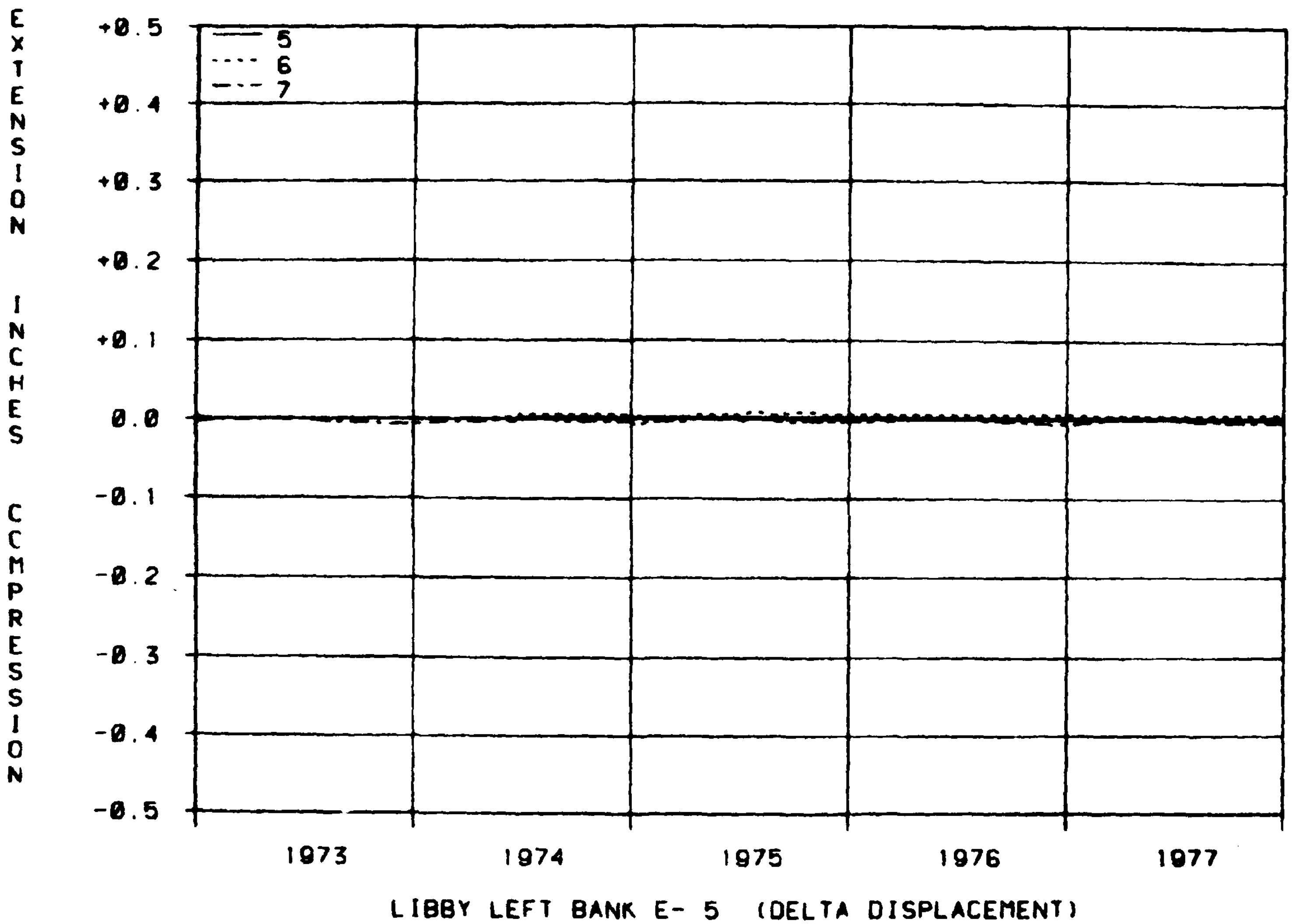

1983
JAN FEB MAR APR MAY JUN JUL AUG SEP OCT NOV DEC
LIBBY LEFT BANK E- 4 (DELTA DISPLACEMENT)
+0.5 +0.4 +0.3 +0.2 +0.1 0.0 -0.1 -0.2 -0.3 -0.4 -0.5
EXTENSION INCHES COMPRESSION


LIBBY LEFT BANK E- 5 (DELTA DISPLACEMENT)
1968
1969
1970
1971
1972
+0.5
+0.4
+0.3
+0.2
+0.1
0.0
-0.1
-0.2
-0.3
-0.4
-0.5
EXTENSION INCHES COMPRESSION
1
2
3
4: 911

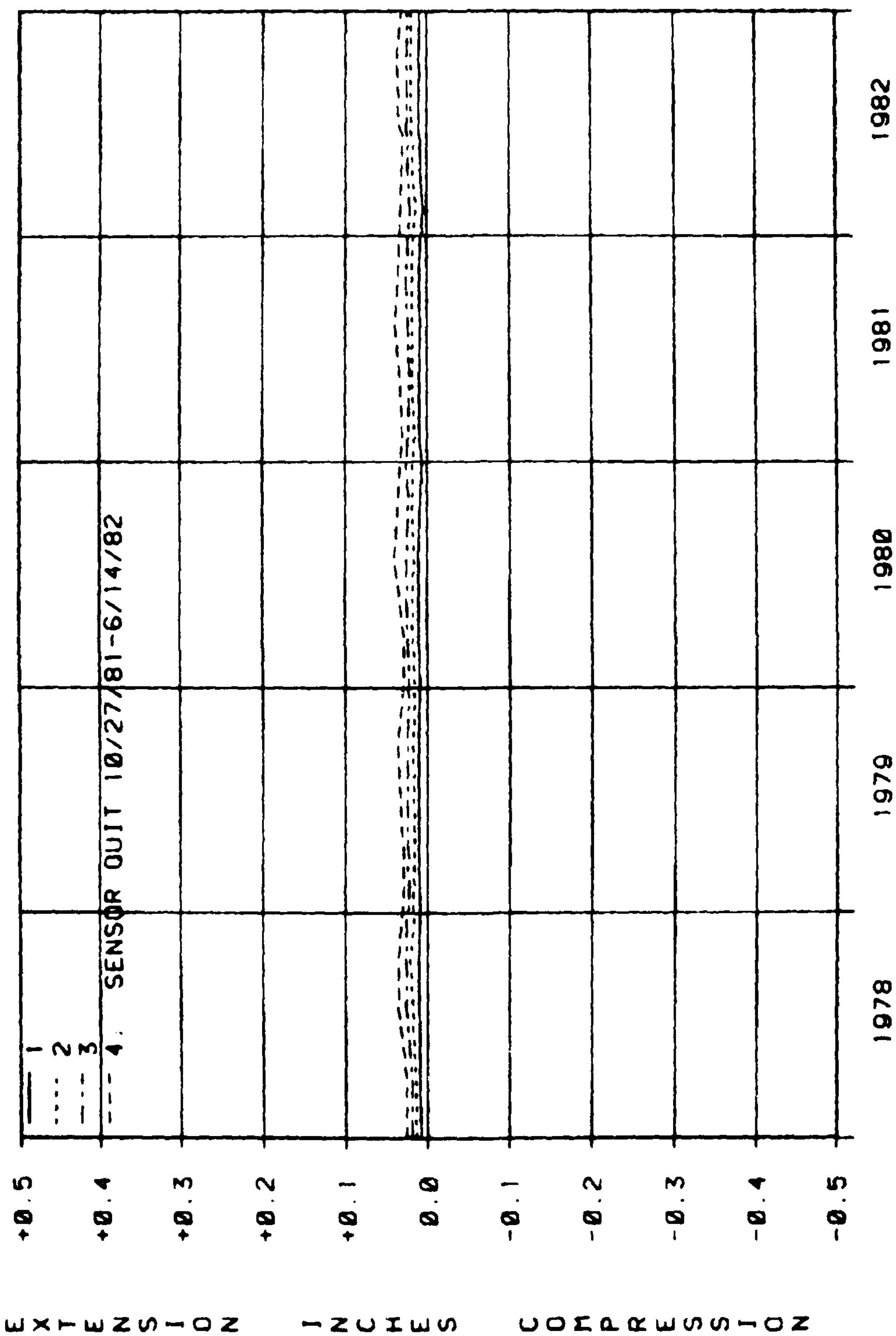

LIBBY LEFT BANK E- 5 (DELTA DISPLACEMENT)
1968
1969
1970
1971
1972
+0.5
+0.4
+0.3
+0.2
+0.1
0.0
-0.1
-0.2
-0.3
-0.4
-0.5
EXTENSION INCHES COMPRESSION
5
6
7



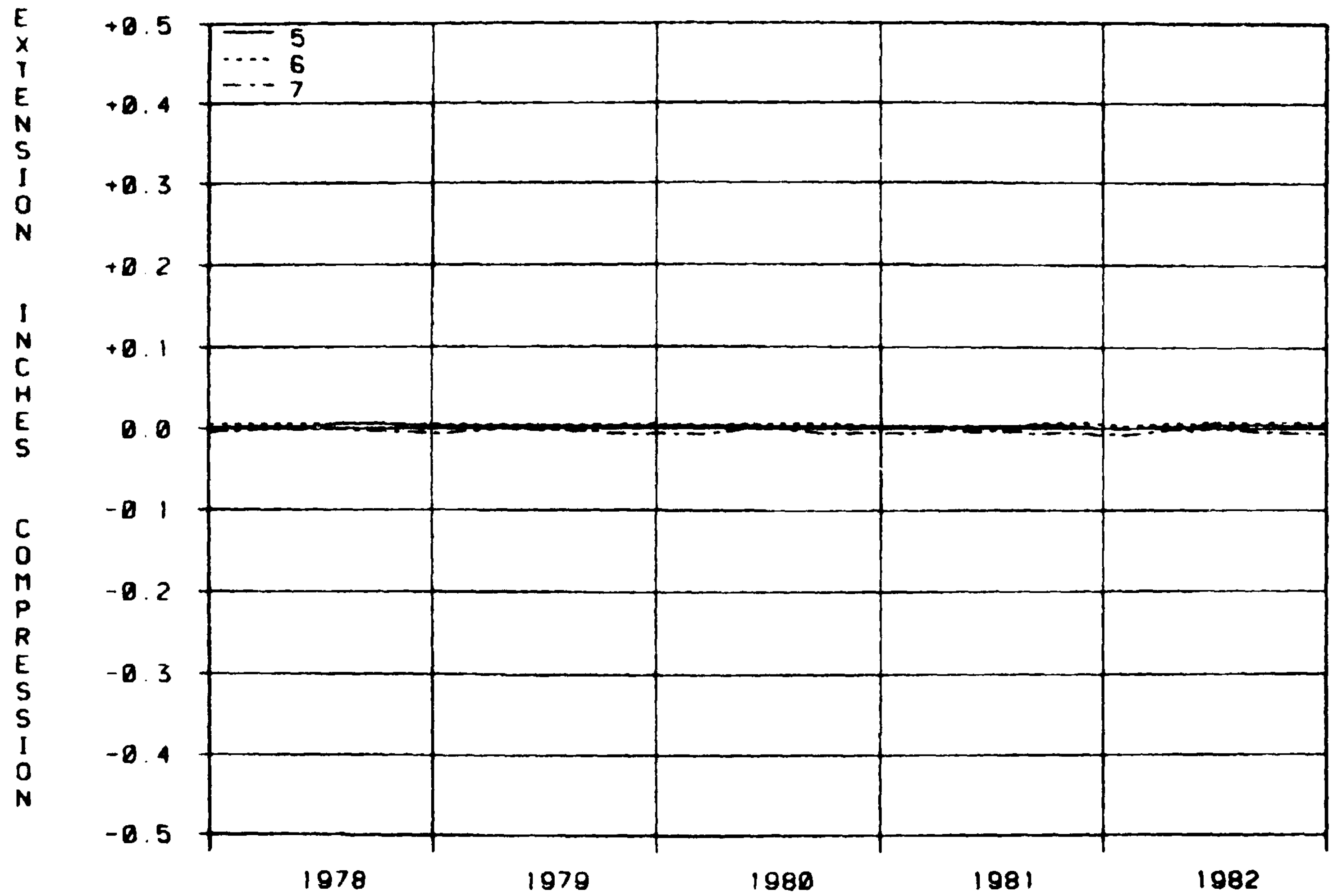
LIBBY LEFT BANK E- 5 (DELTA DISPLACEMENT)



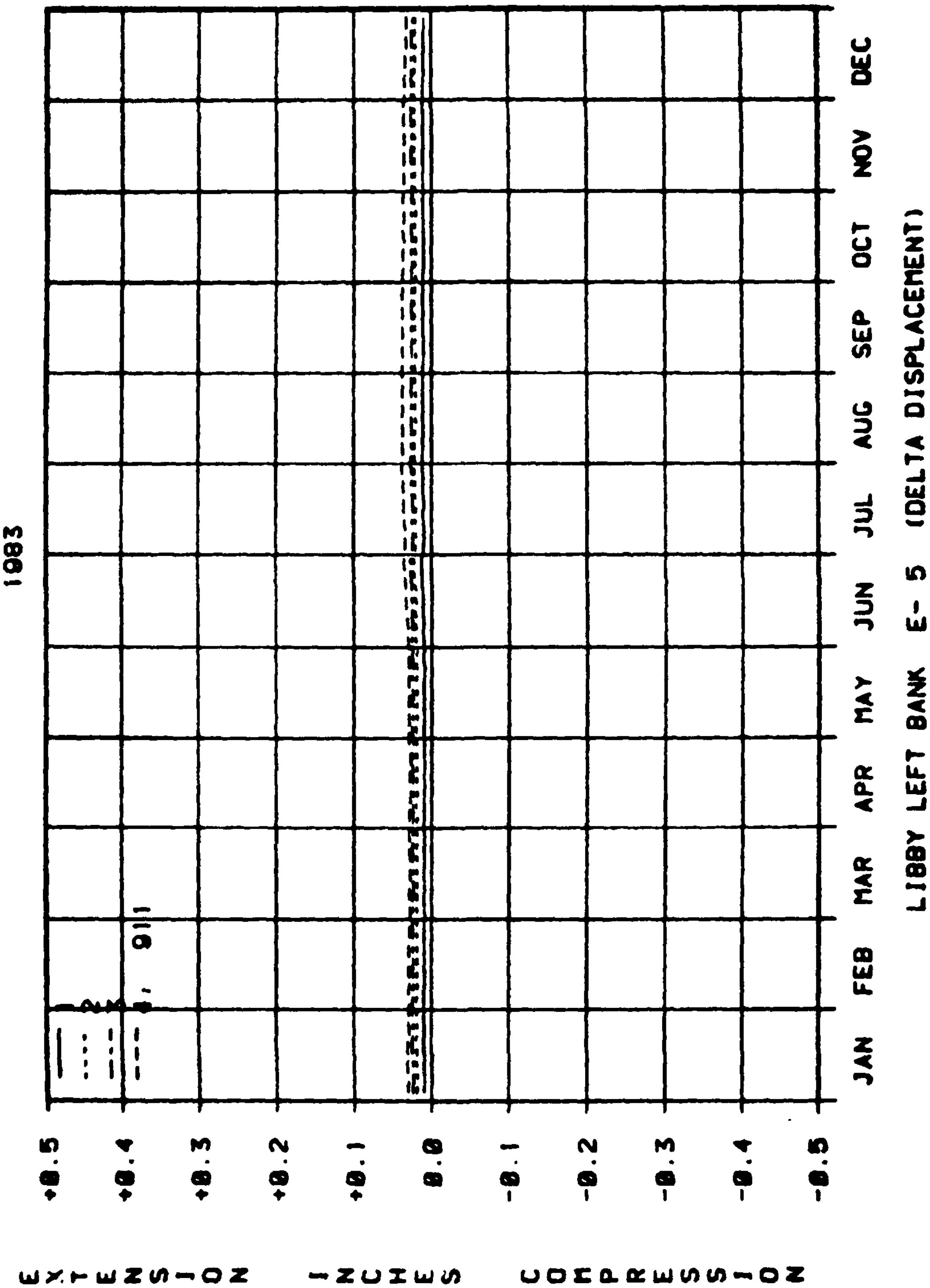
EXTENSION INCHES COMPRESSION
+0.5
+0.4
+0.3
+0.2
+0.1
0.0
-0.1
-0.2
-0.3
-0.4
-0.5
5
6
7
1973
1974
1975
1976
1977
LIBBY LEFT BANK E- 5 (DELTA DISPLACEMENT)

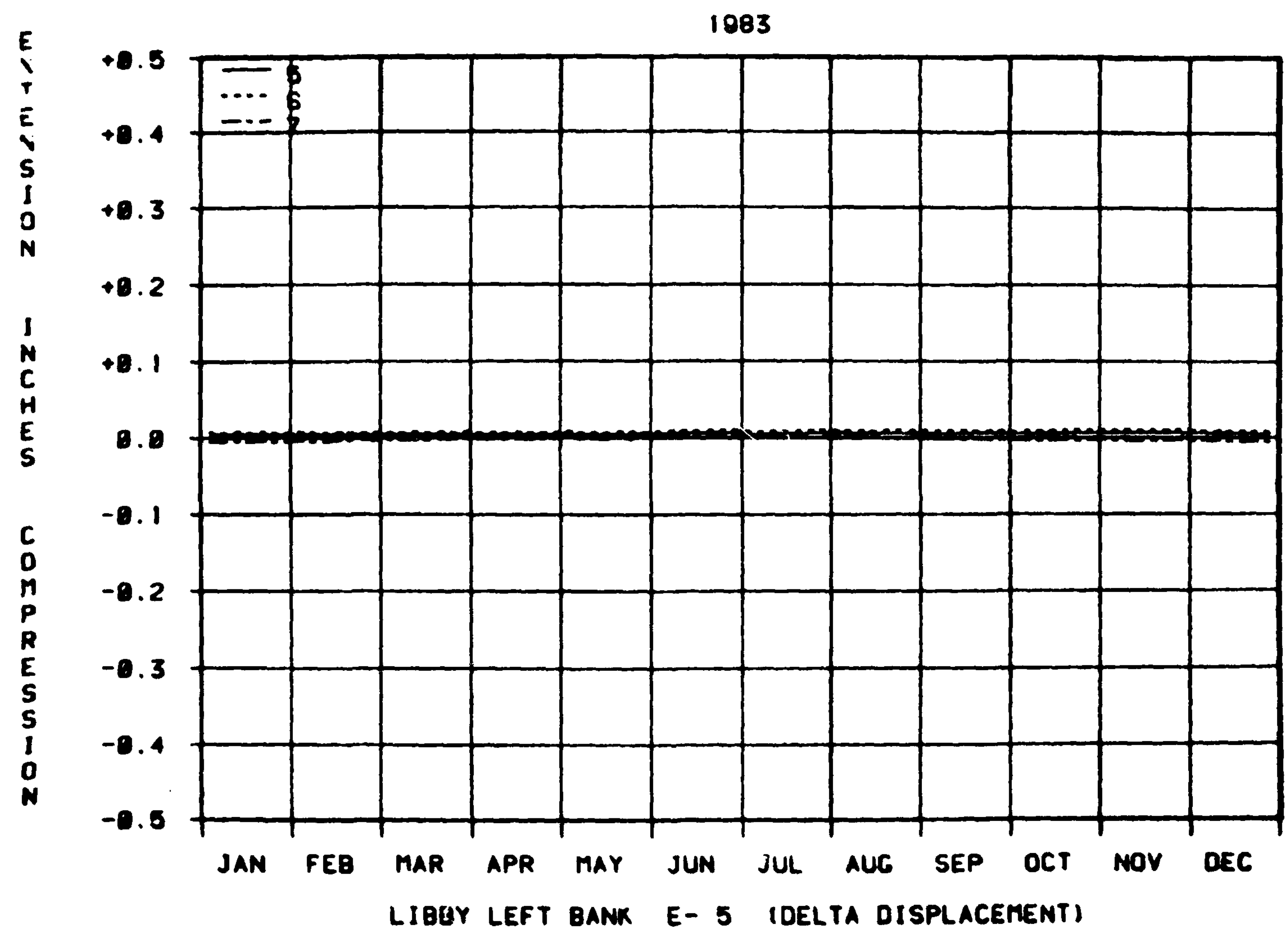


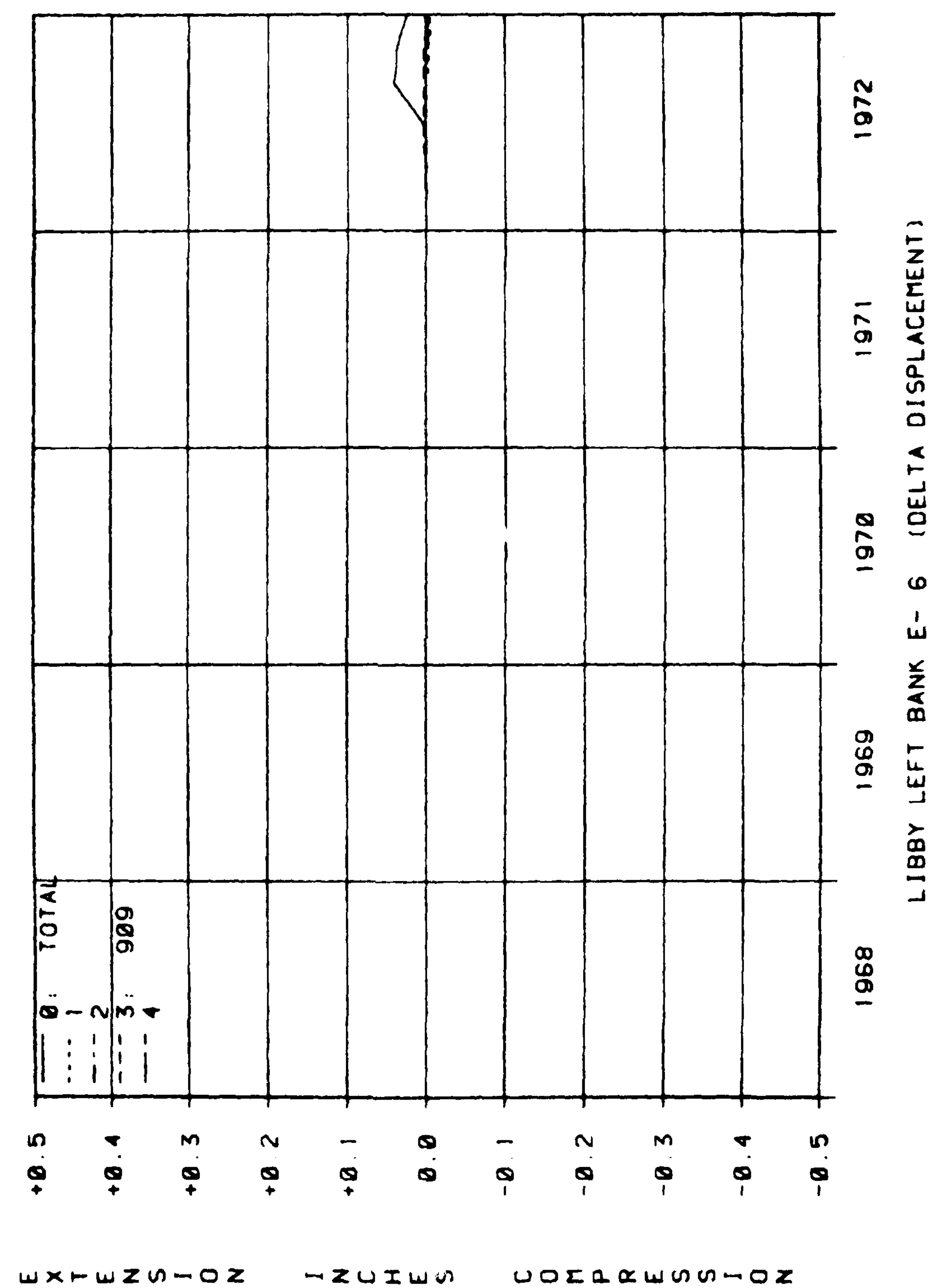
LIBBY LEFT BANK E- 5 (DELTA DISPLACEMENT)



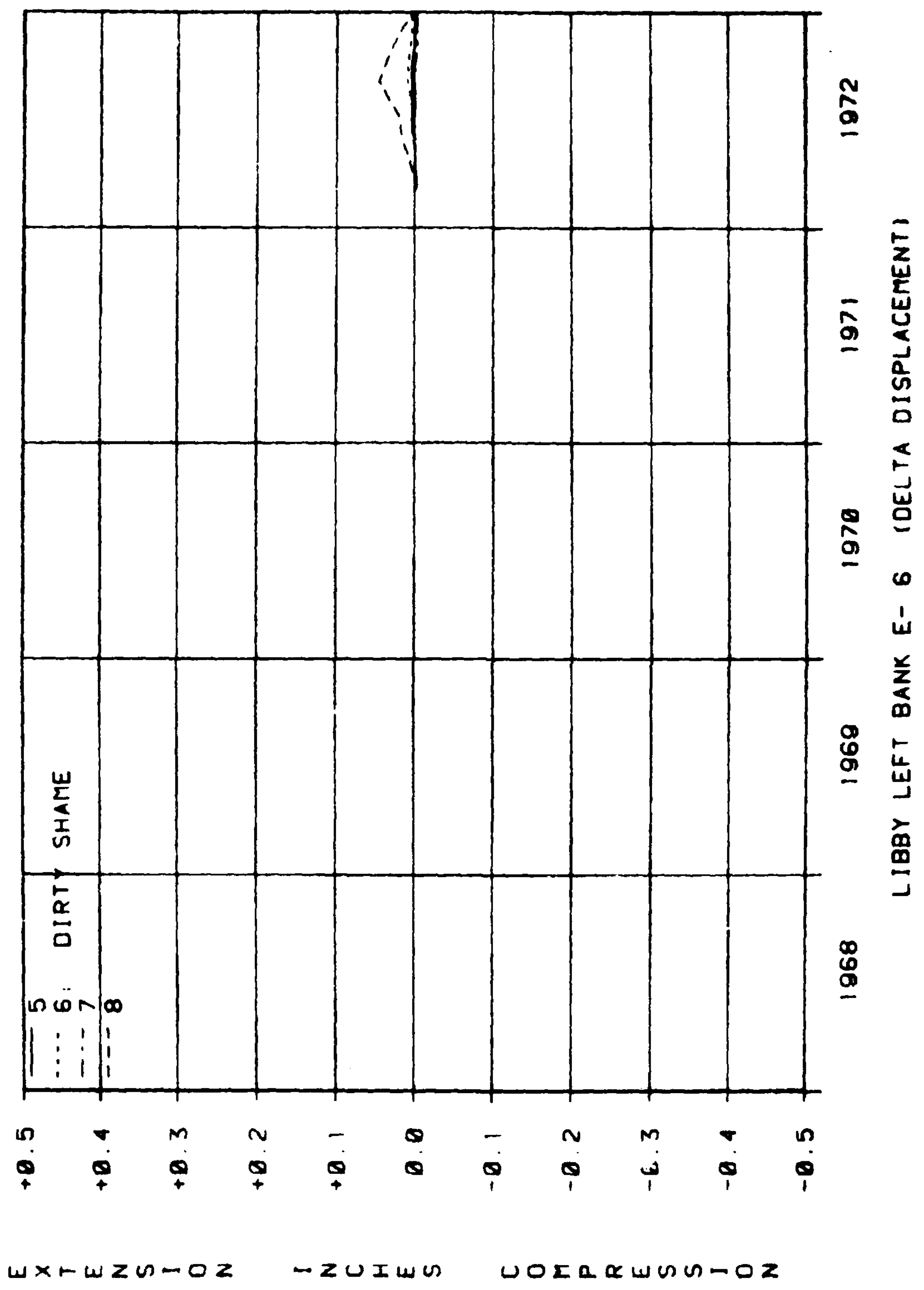
LIBBY LEFT BANK E- 5 (DELTA DISPLACEMENT)


1983
LIBBY LEFT BANK E- 5 (DELTA DISPLACEMENT)
JAN FEB MAR APR MAY JUN JUL AUG SEP OCT NOV DEC
+0.5 +0.4 +0.3 +0.2 +0.1 0.0 -0.1 -0.2 -0.3 -0.4 -0.5
EXTENSION INCHES COMPRESSION

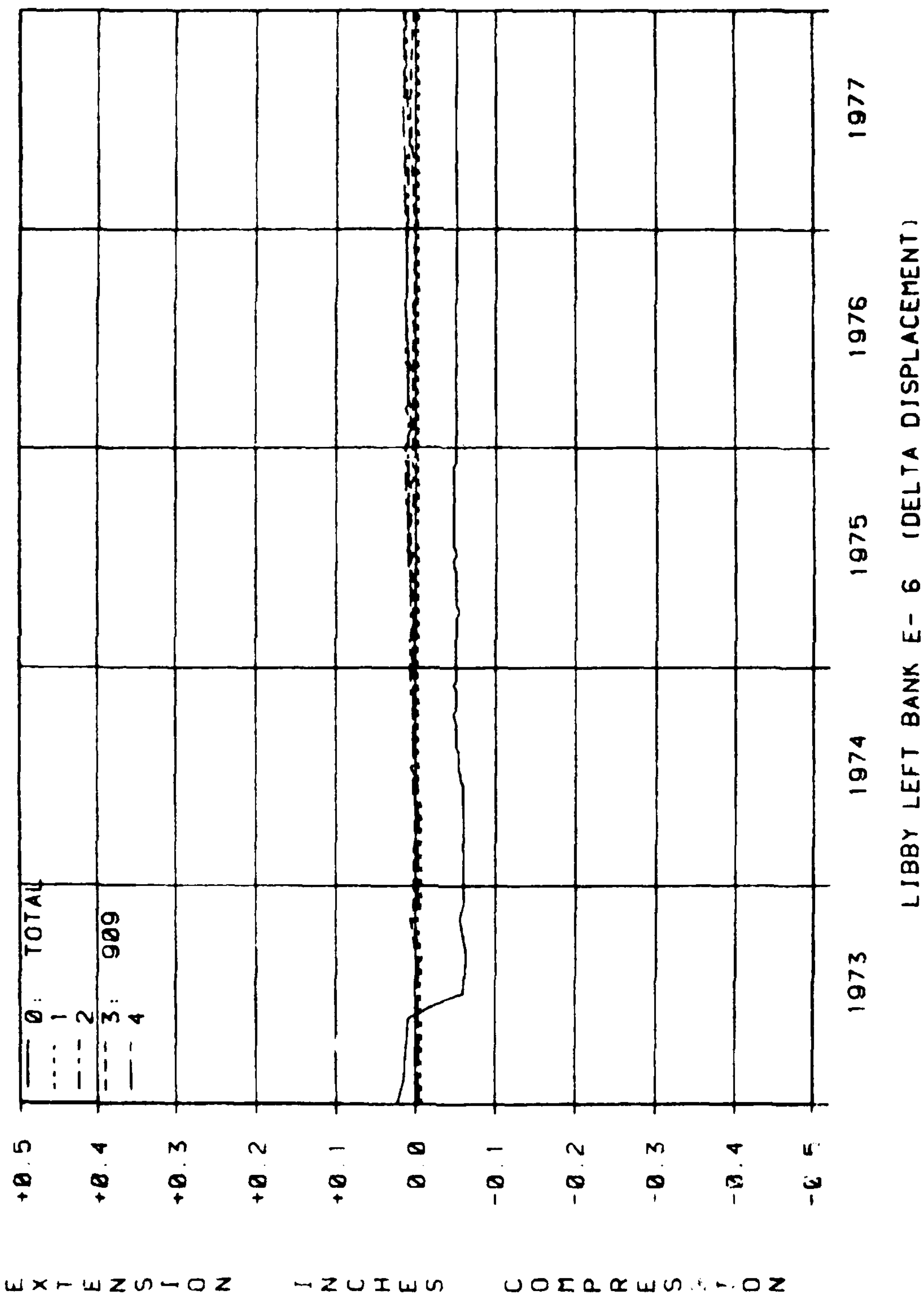

1983
EXTENSION INCHES COMPRESSION
+0.5
+0.4
+0.3
+0.2
+0.1
0.0
-0.1
-0.2
-0.3
-0.4
-0.5
5
6
7
JAN FEB MAR APR MAY JUN JUL AUG SEP OCT NOV DEC
LIBBY LEFT BANK E- 5 (DELTA DISPLACEMENT)

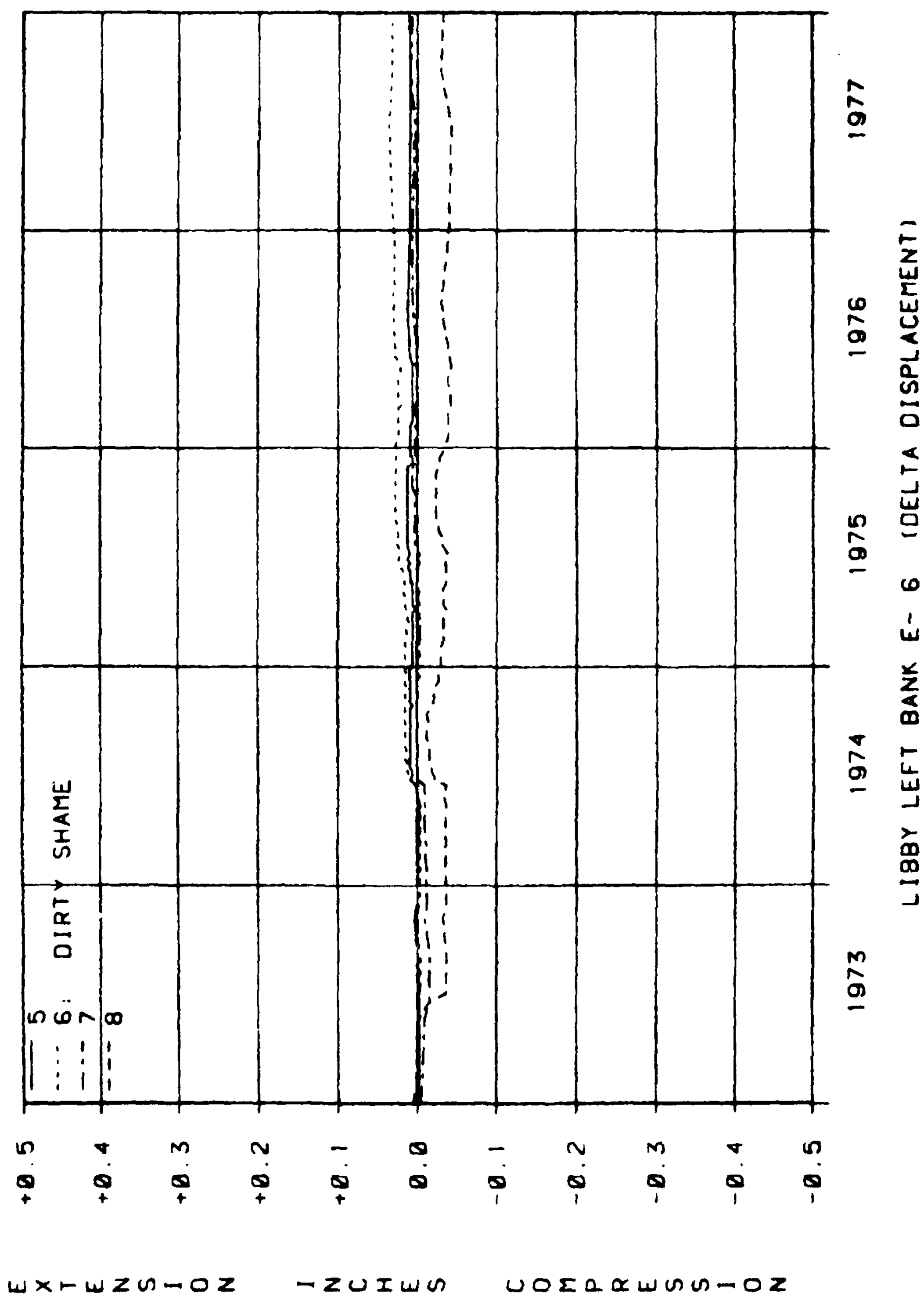


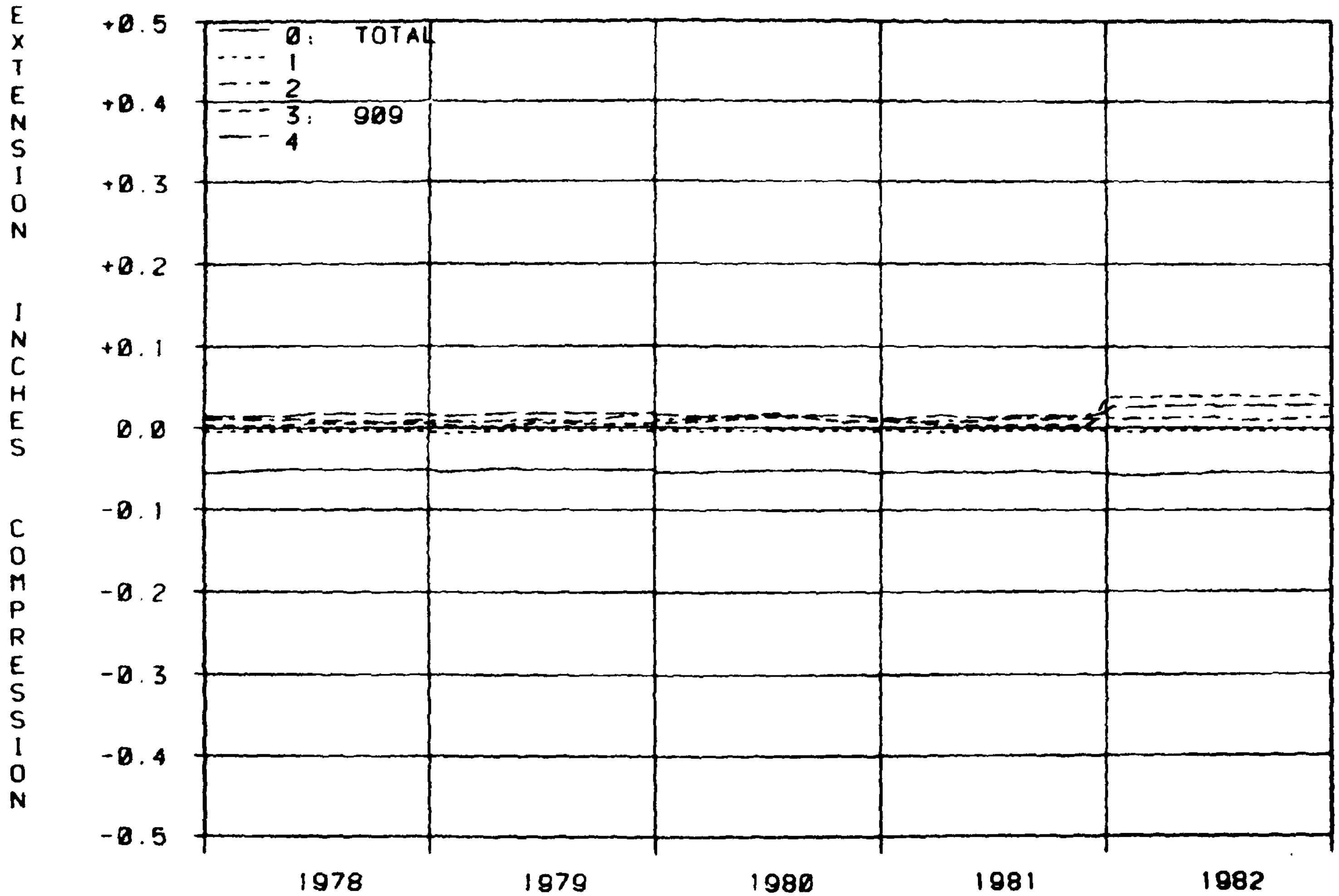
LIBBY LEFT BANK E- 6 (DELTA DISPLACEMENT)
1968
1969
1970
1971
1972
0: TOTAL
1
2
3: 909
4
+0.5
+0.4
+0.3
+0.2
+0.1
0.0
-0.1
-0.2
-0.3
-0.4
-0.5
EXTENSION INCHES COMPRESSION



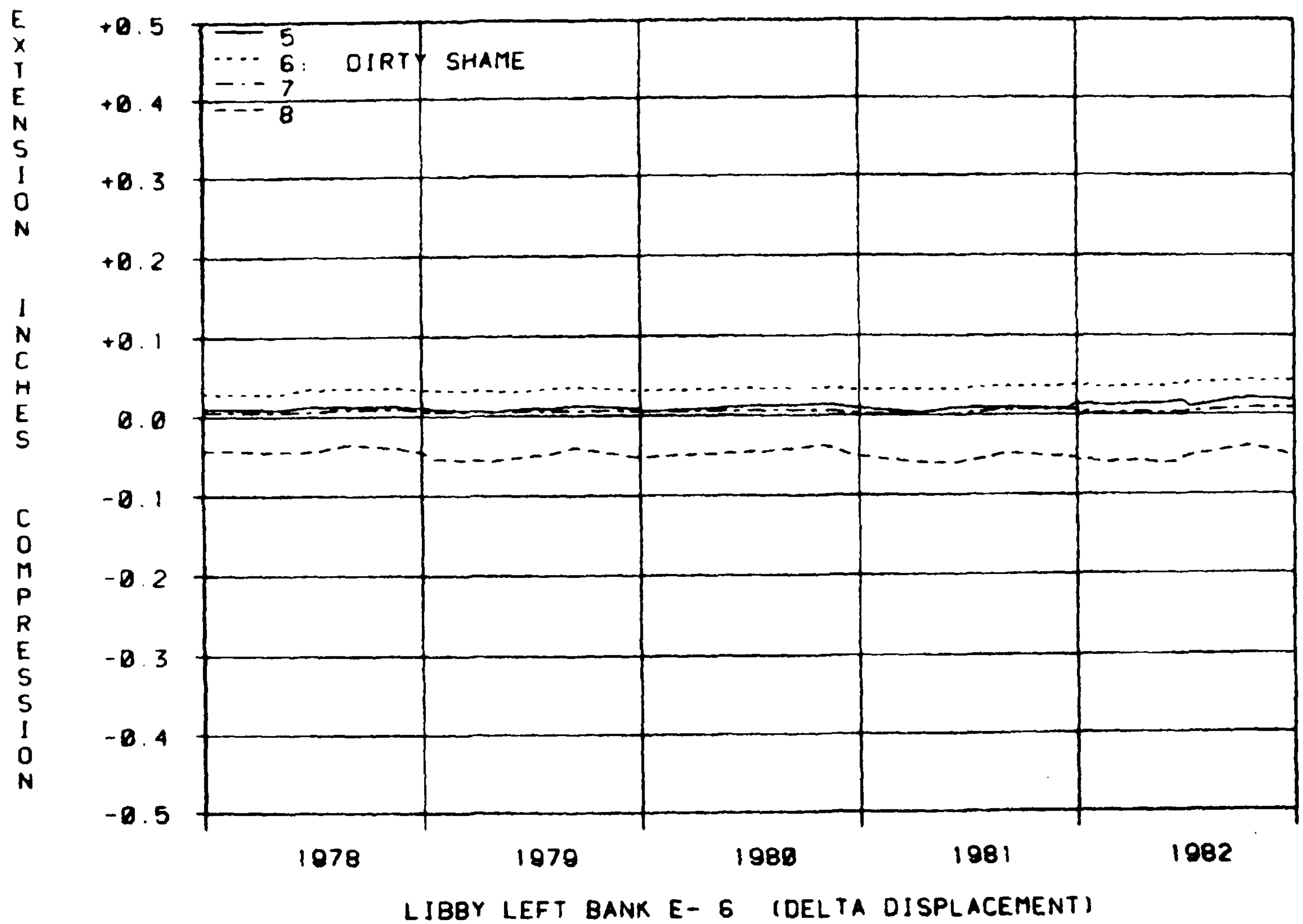
LIBBY LEFT BANK E- 6 (DELTA DISPLACEMENT)
DIRTY SHAME
5
6
7
8
1968
1969
1970
1971
1972
+0.5
+0.4
+0.3
+0.2
+0.1
0.0
-0.1
-0.2
-0.3
-0.4
-0.5
EXTENSION INCHES COMPRESSION

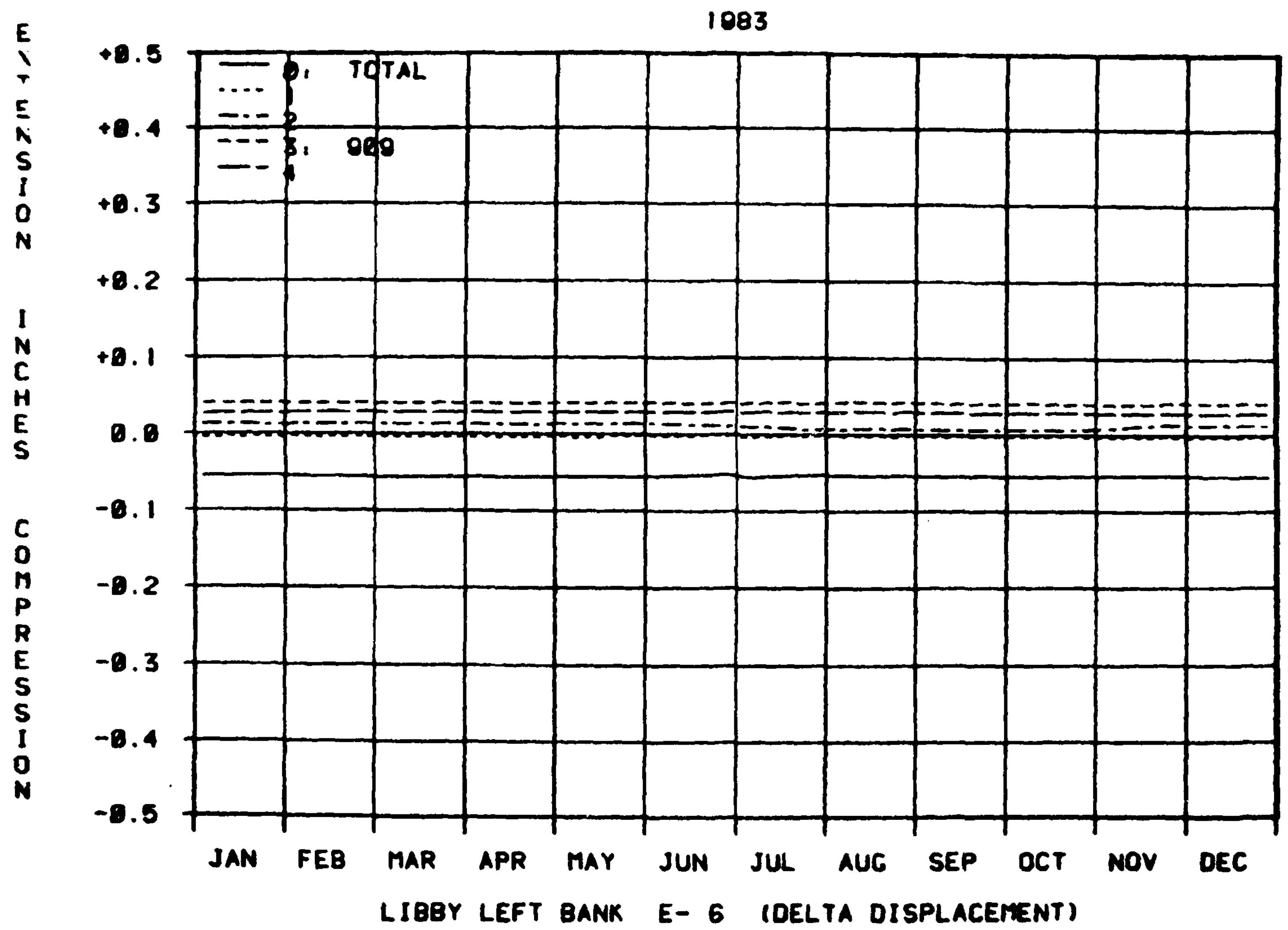

LIBBY LEFT BANK E- 6 (DELTA DISPLACEMENT)
1973
1974
1975
1976
1977
0: TOTAL
1
2
3: 909
4
+0.5
+0.4
+0.3
+0.2
+0.1
0.0
-0.1
-0.2
-0.3
-0.4
-0.5
EXTENSION INCHES COMPRESSION


LIBBY LEFT BANK E- 6 (DELTA DISPLACEMENT)
5
6
7
8
DIRTY SHAME
1973
1974
1975
1976
1977
+0.5
+0.4
+0.3
+0.2
+0.1
0.0
-0.1
-0.2
-0.3
-0.4
-0.5
EXTENSION
INCHES
COMPRESSION

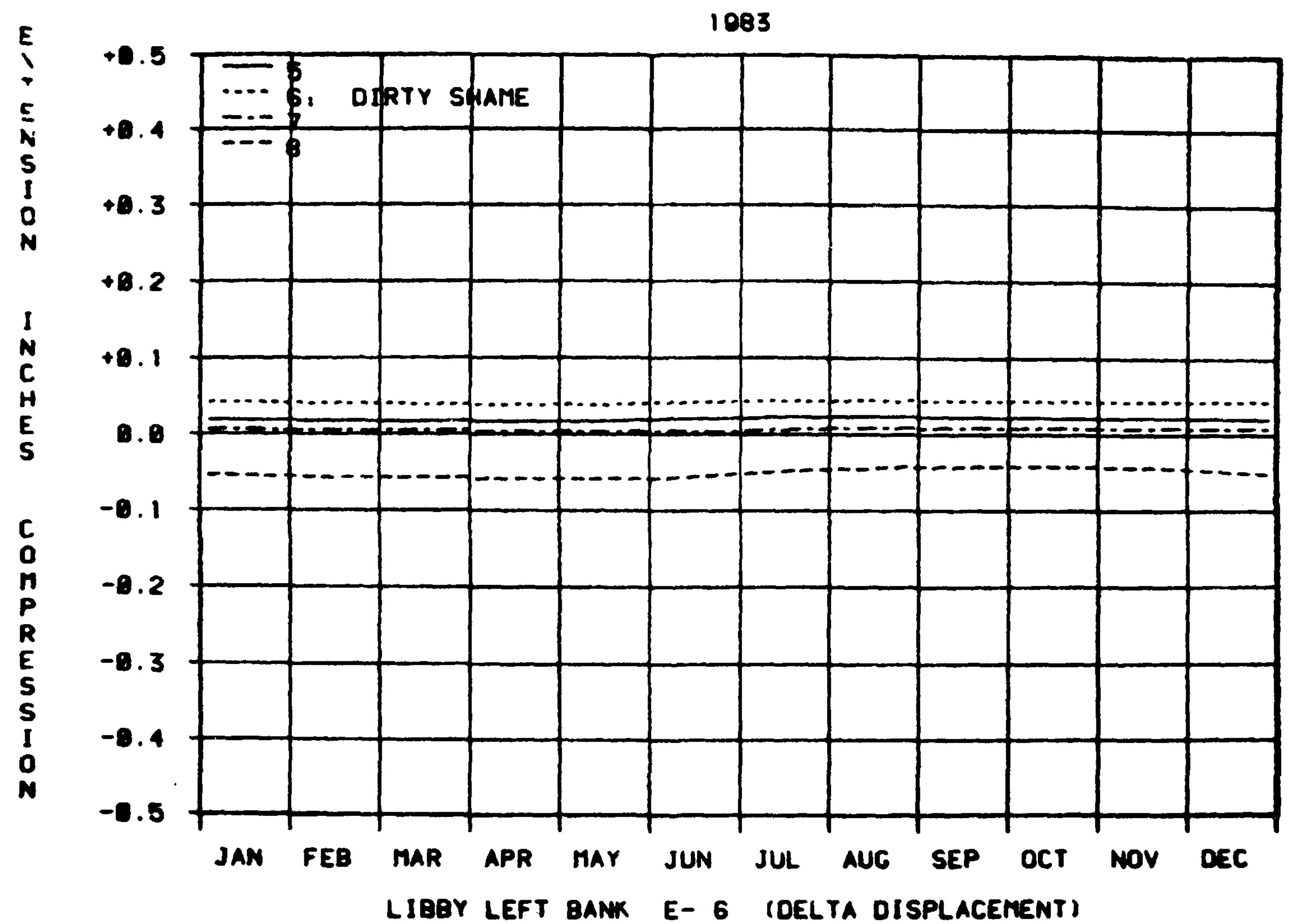


LIBBY LEFT BANK E- 6 (DELTA DISPLACEMENT)

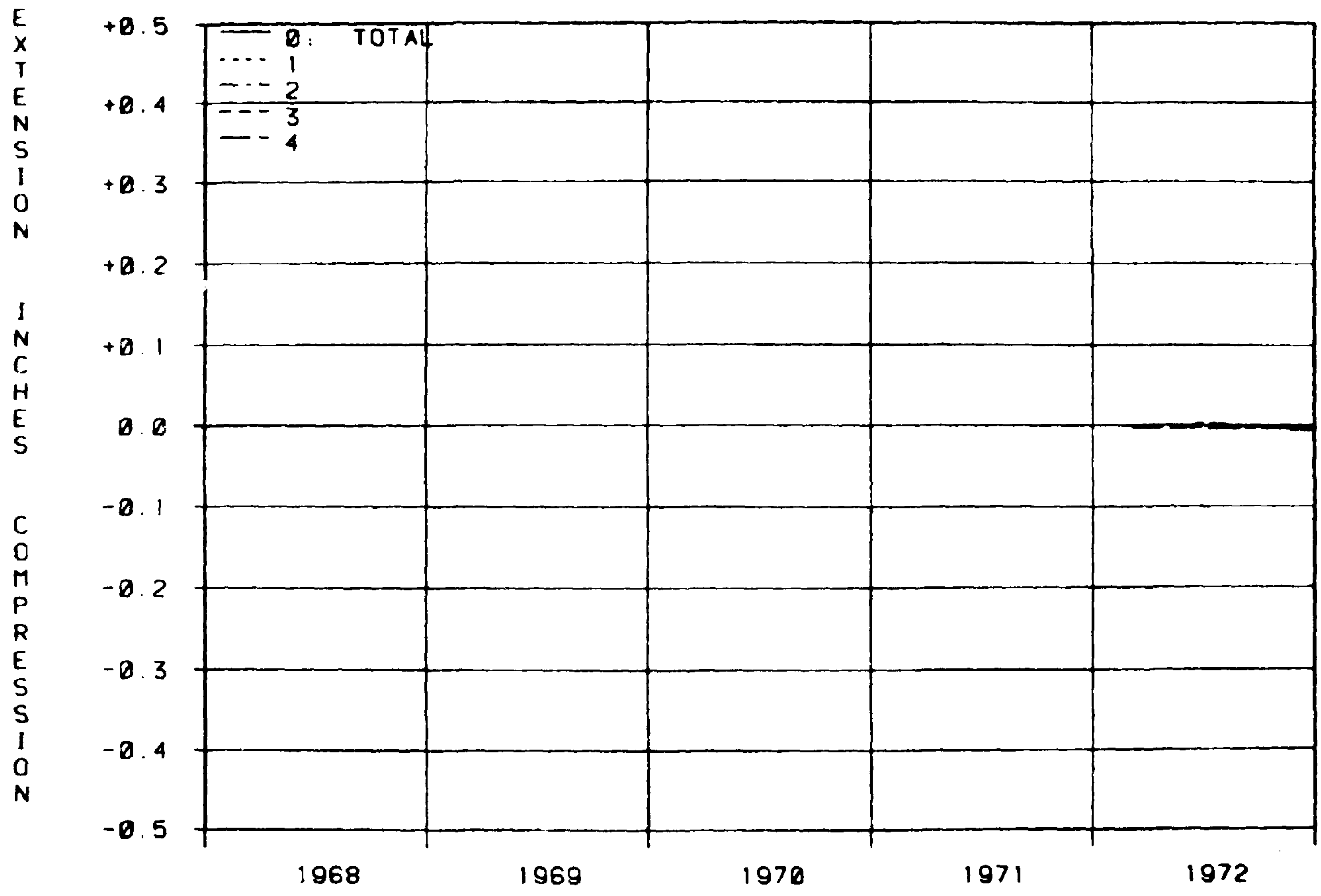

5
6: DIRTY SHAME
7
8
EXTENSION INCHES COMPRESSION
+0.5
+0.4
+0.3
+0.2
+0.1
0.0
-0.1
-0.2
-0.3
-0.4
-0.5
1978
1979
1980
1981
1982
LIBBY LEFT BANK E- 6 (DELTA DISPLACEMENT)



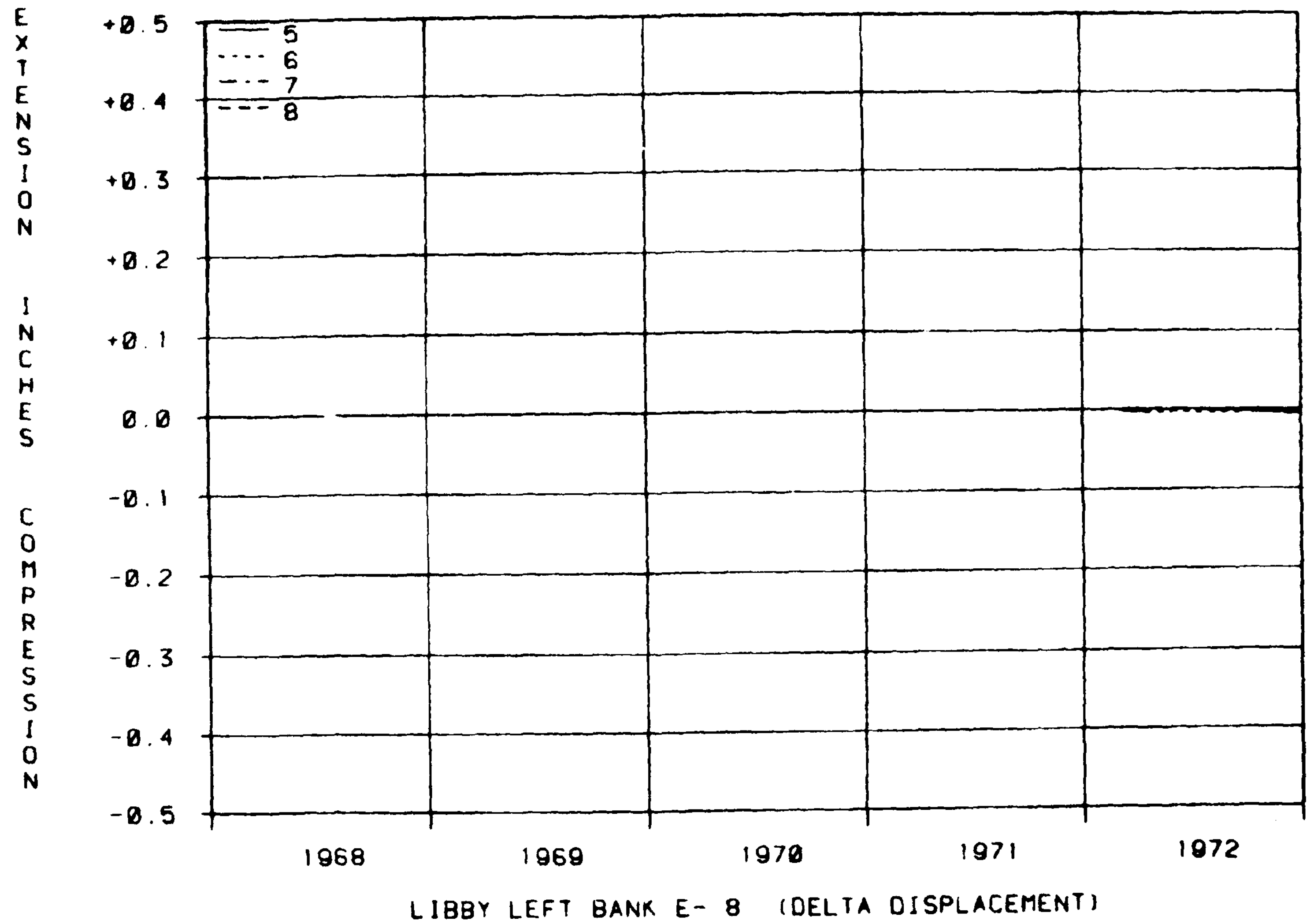
1983
0: TOTAL
1
2
3: 909
4
E/TENSION INCHES COMPRESSION
+0.5
+0.4
+0.3
+0.2
+0.1
0.0
-0.1
-0.2
-0.3
-0.4
-0.5
JAN FEB MAR APR MAY JUN JUL AUG SEP OCT NOV DEC
LIBBY LEFT BANK E- 6 (DELTA DISPLACEMENT)

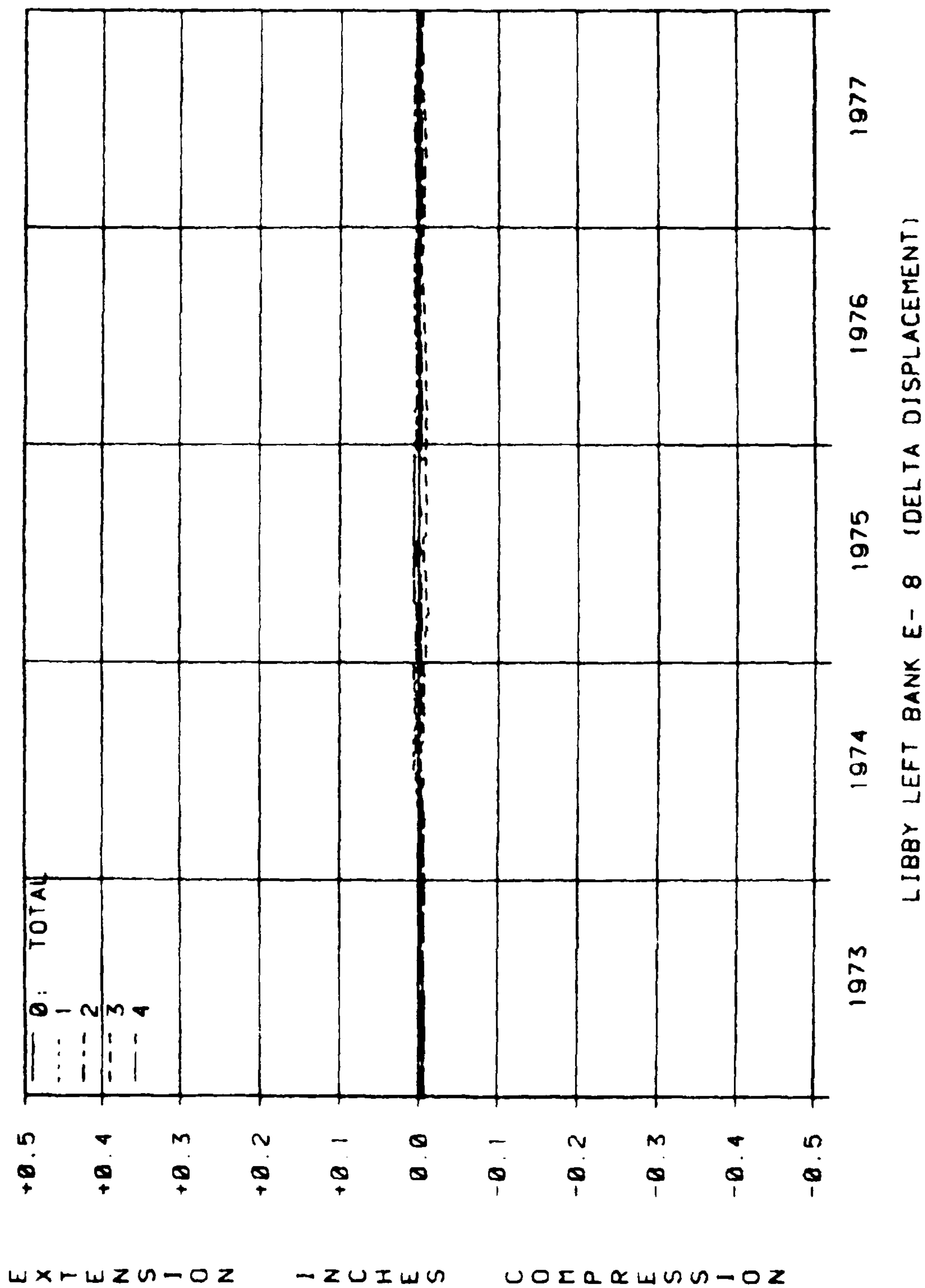


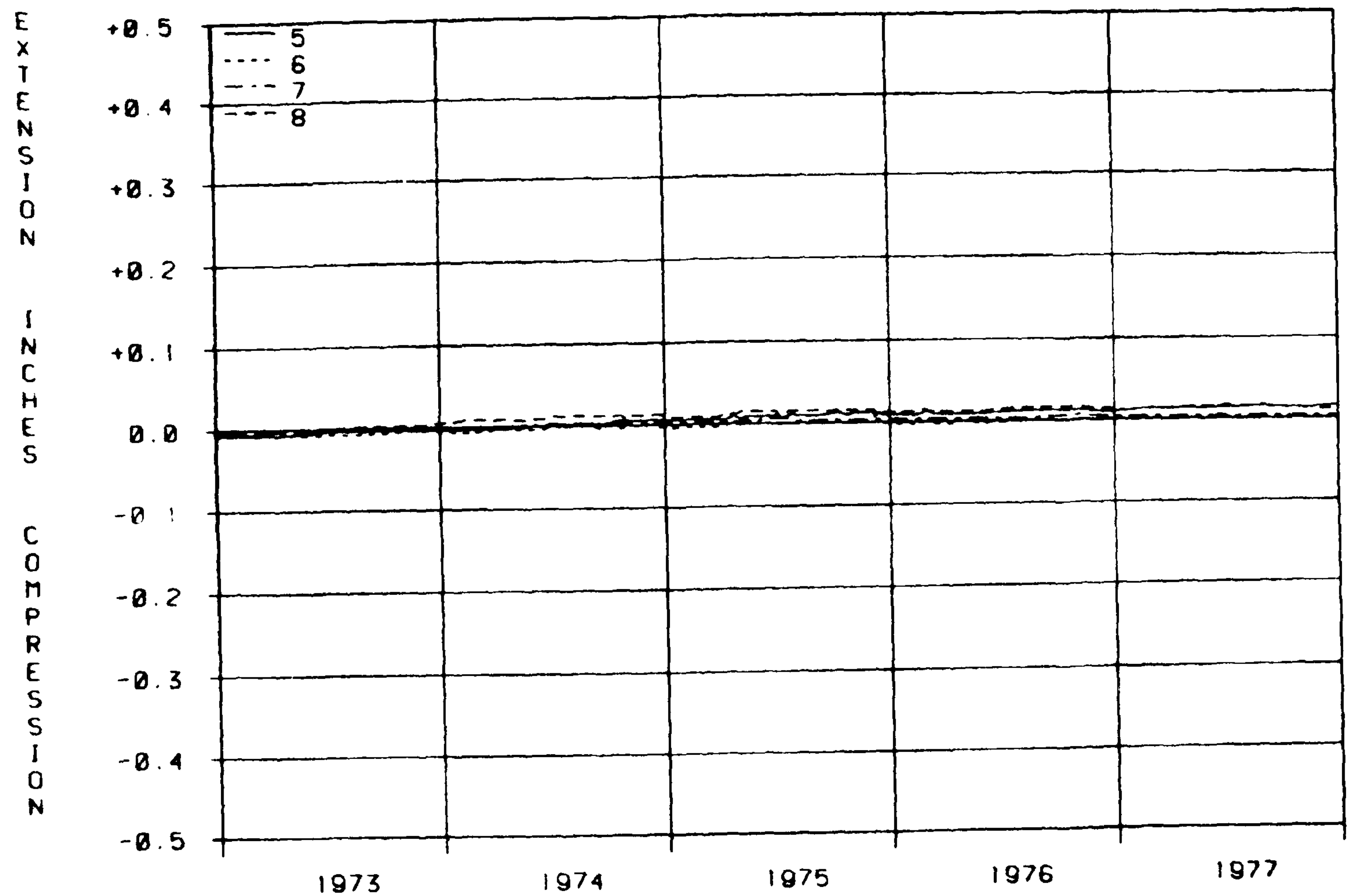
1983
E/TENSION INCHES COMPRESSION
+0.5
+0.4
+0.3
+0.2
+0.1
0.0
-0.1
-0.2
-0.3
-0.4
-0.5
5
6: DIRTY SHAME
7
8
JAN FEB MAR APR MAY JUN JUL AUG SEP OCT NOV DEC
LIBBY LEFT BANK E- 6 (DELTA DISPLACEMENT)



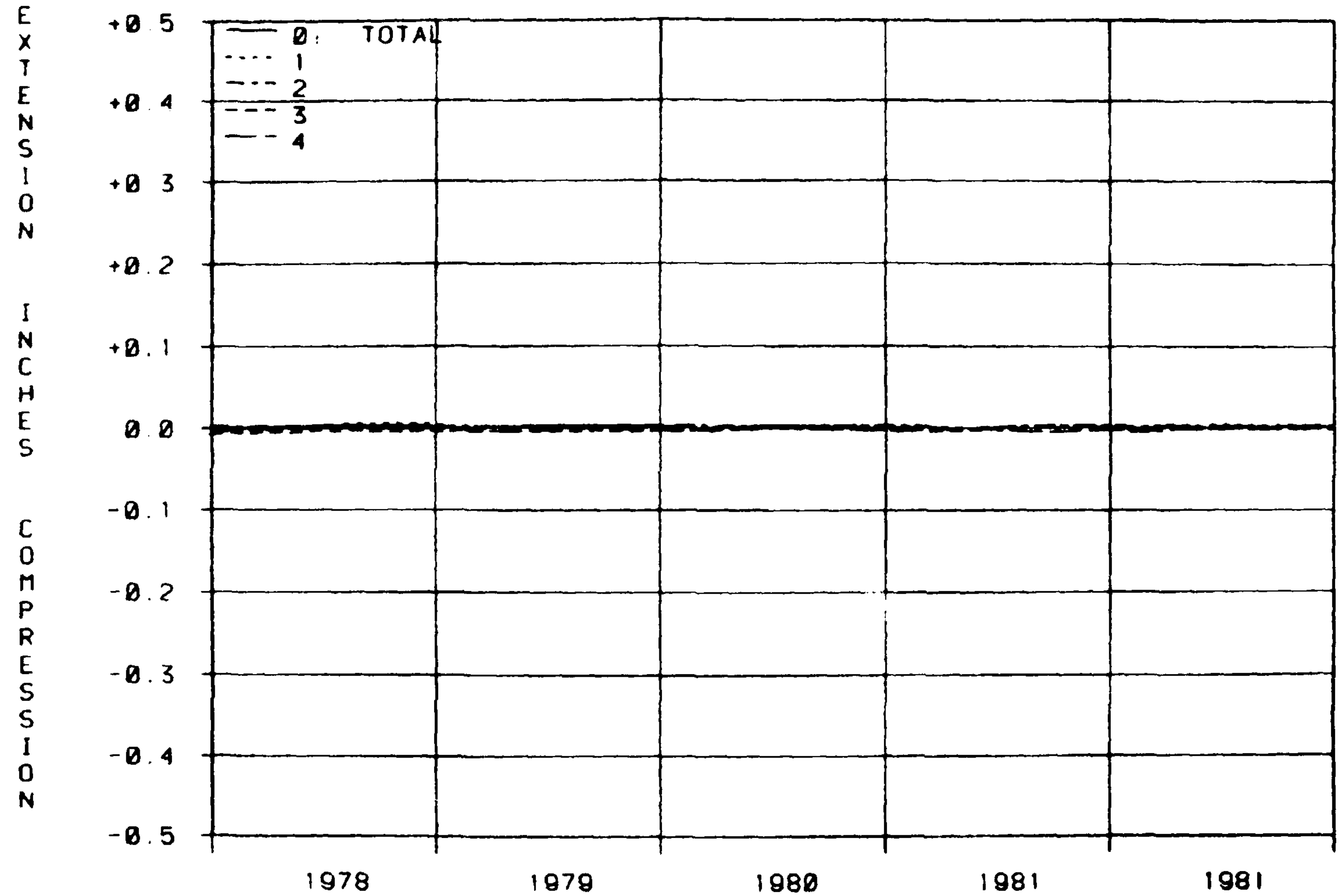
LIBBY LEFT BANK E- 8 (DELTA DISPLACEMENT)


EXTENSION INCHES COMPRESSION
+0.5
+0.4
+0.3
+0.2
+0.1
0.0
-0.1
-0.2
-0.3
-0.4
-0.5
5
6
7
8
1968
1969
1970
1971
1972
LIBBY LEFT BANK E- 8 (DELTA DISPLACEMENT)

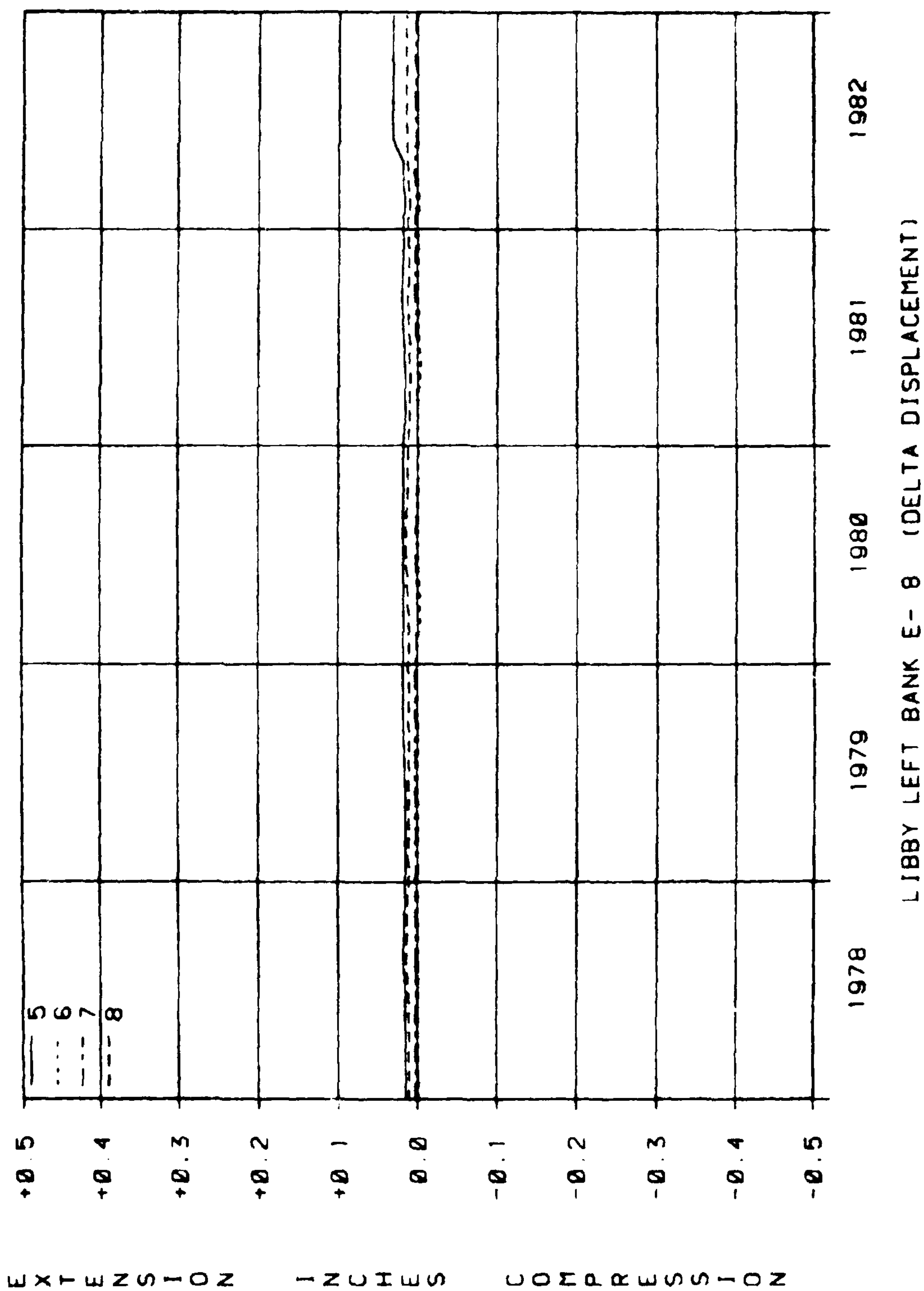

LIBBY LEFT BANK E- 8 (DELTA DISPLACEMENT)
1973
1974
1975
1976
1977
+0.5
+0.4
+0.3
+0.2
+0.1
0.0
-0.1
-0.2
-0.3
-0.4
-0.5
EXTENSION INCHES COMPRESSION
0: TOTAL
1
2
3
4



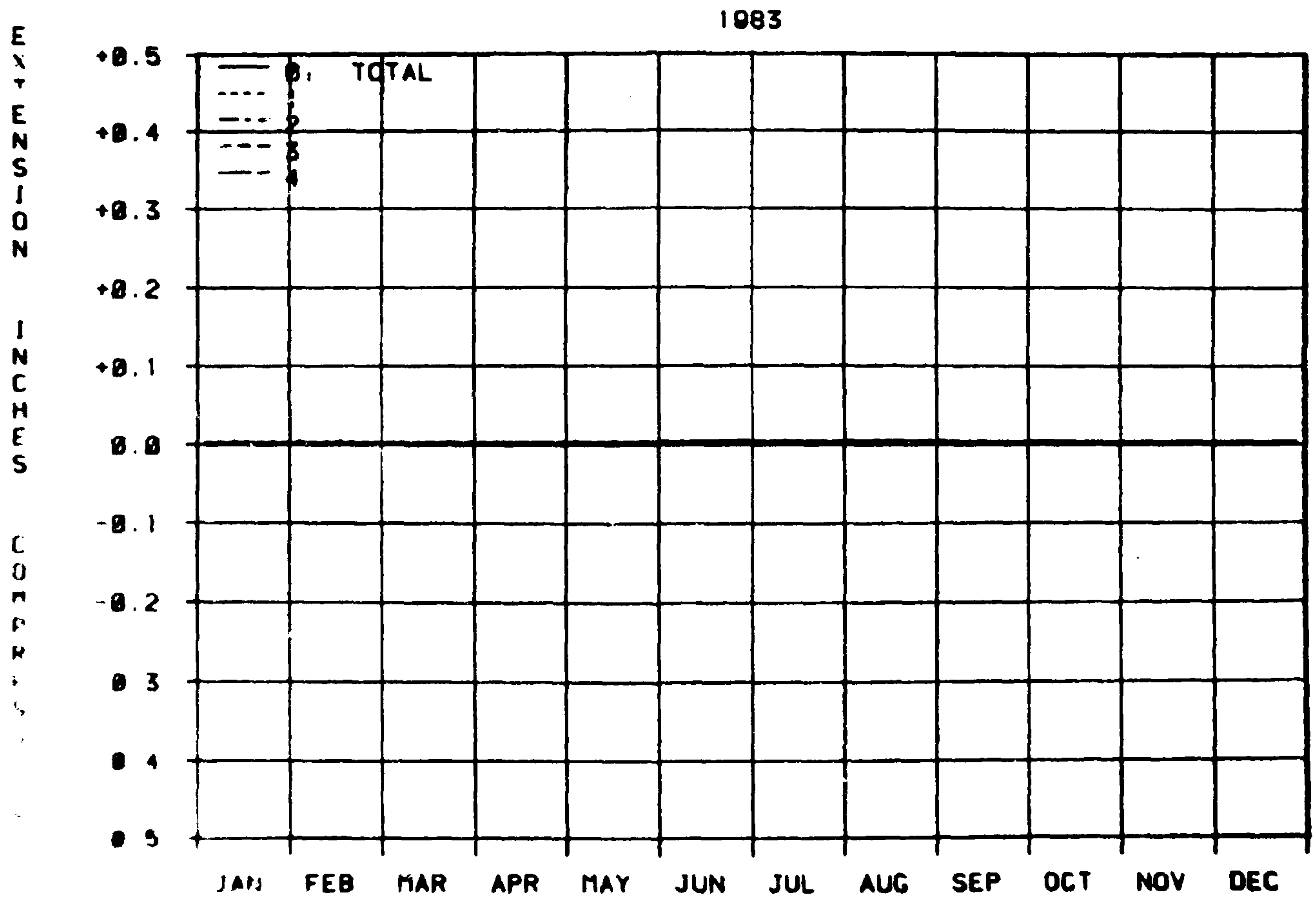
LIBBY LEFT BANK E- 8 (DELTA DISPLACEMENT)



LIBBY LEFT BANK E- 8 (DELTA DISPLACEMENT)



LIBBY LEFT BANK E- 8 (DELTA DISPLACEMENT)
1978
1979
1980
1981
1982
+0.5
+0.4
+0.3
+0.2
+0.1
0.0
-0.1
-0.2
-0.3
-0.4
-0.5
EXTENSION INCHES COMPRESSION
5
6
7
8

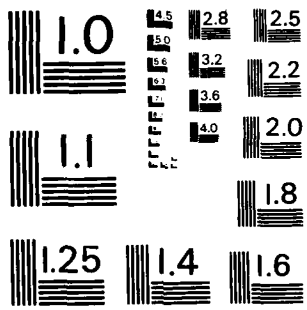


LIBBY LEFT BANK E- 8 (DELTA DISPLACEMENT)

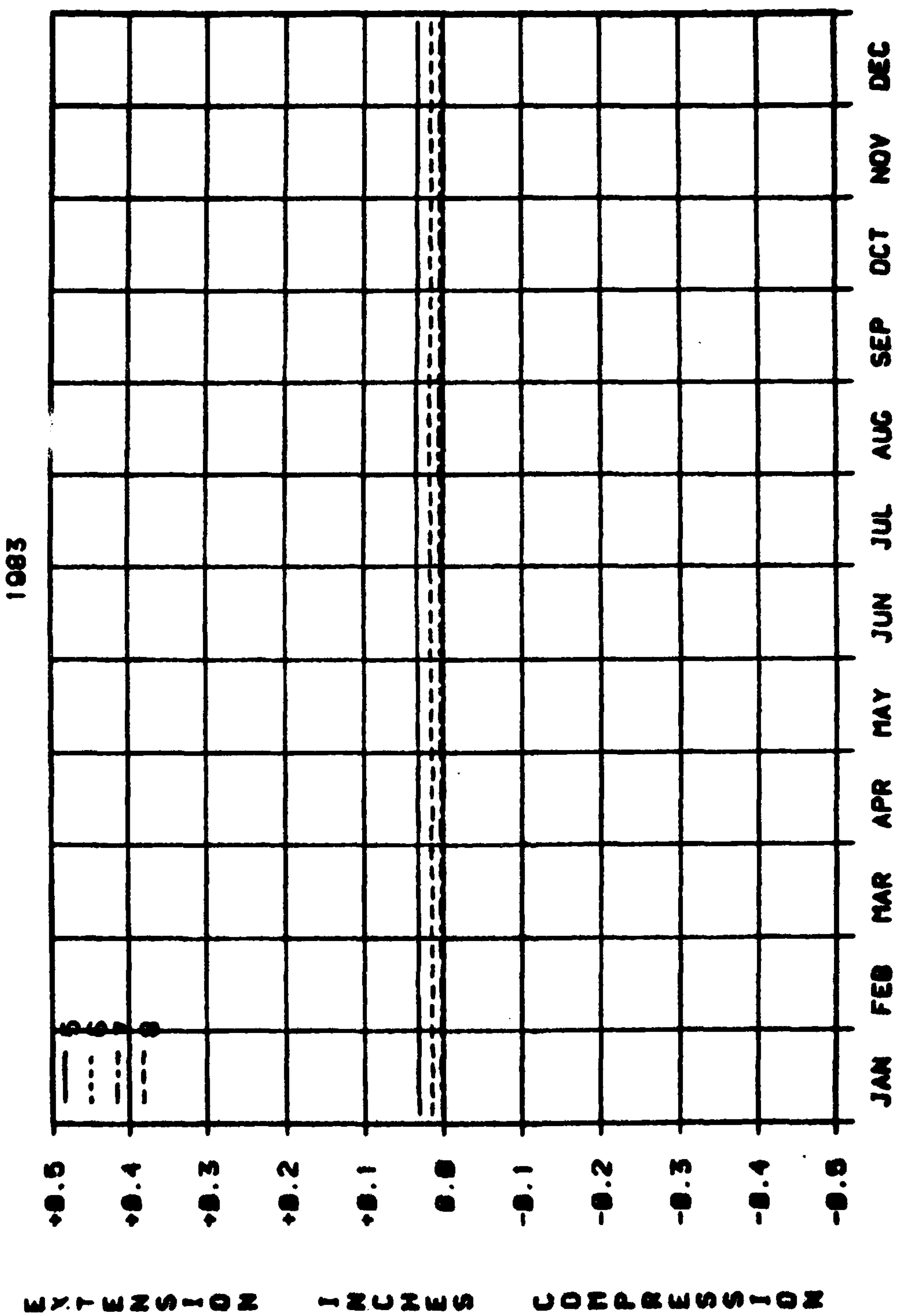
AD-A142 021 LIBBY DAM AND LAKE KOOCANUSA PROJECT MONTANA LEFT BANK SLOPE(U) CORPS OF ENGINEERS SEATTLE WA SEATTLE DISTRICT APR 84

5/6

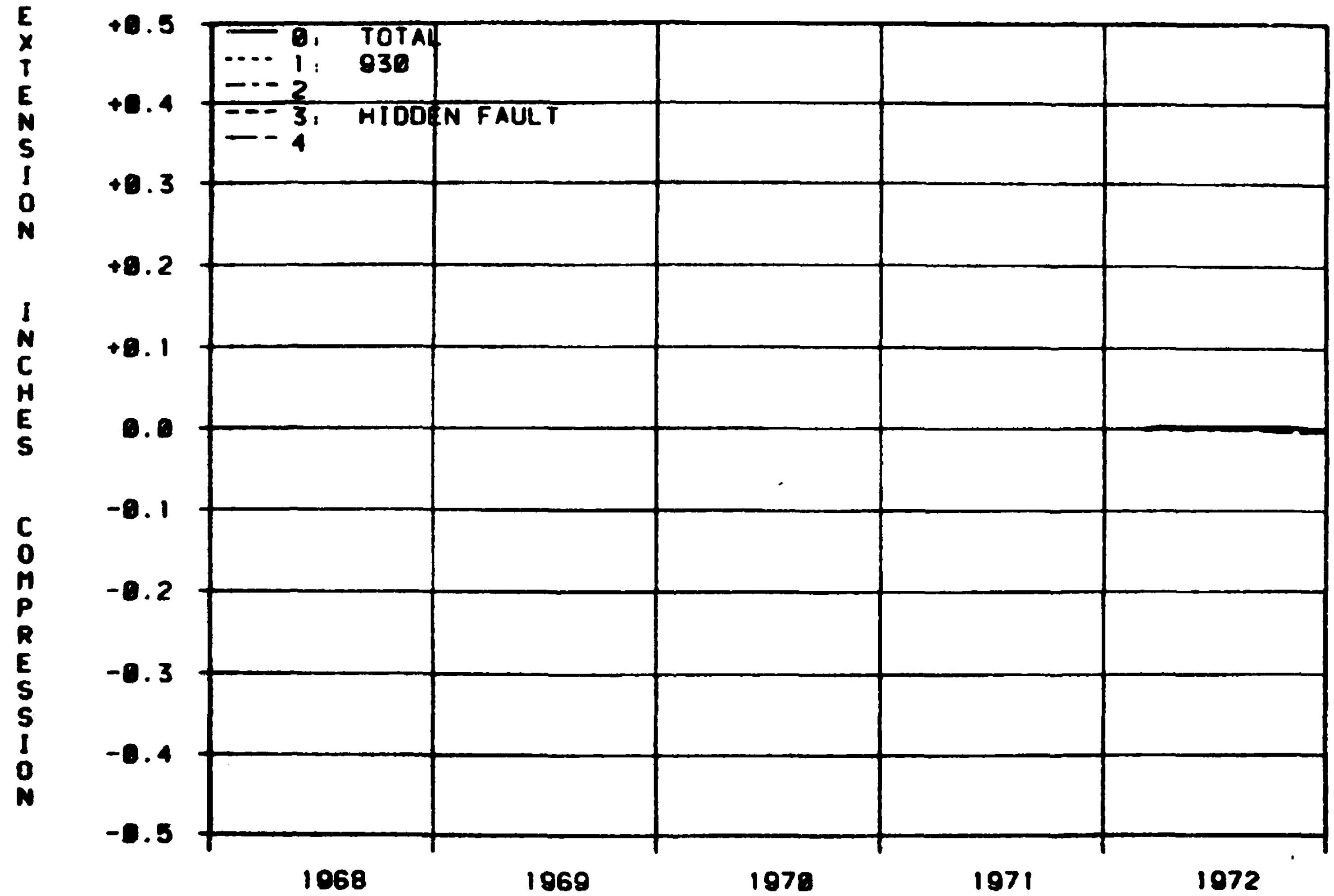
UNCLASSIFIED F/G 13/2 NL



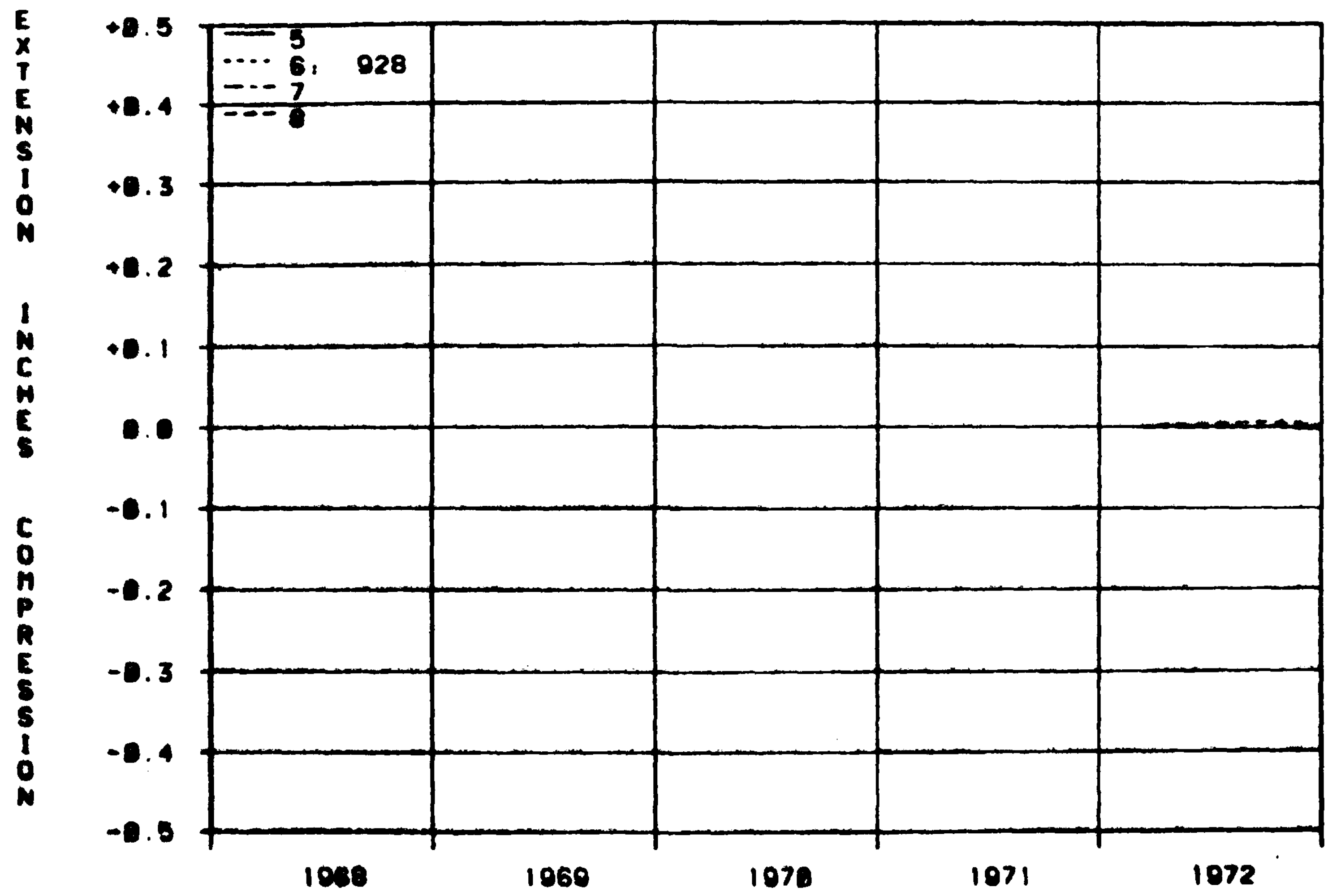
MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A



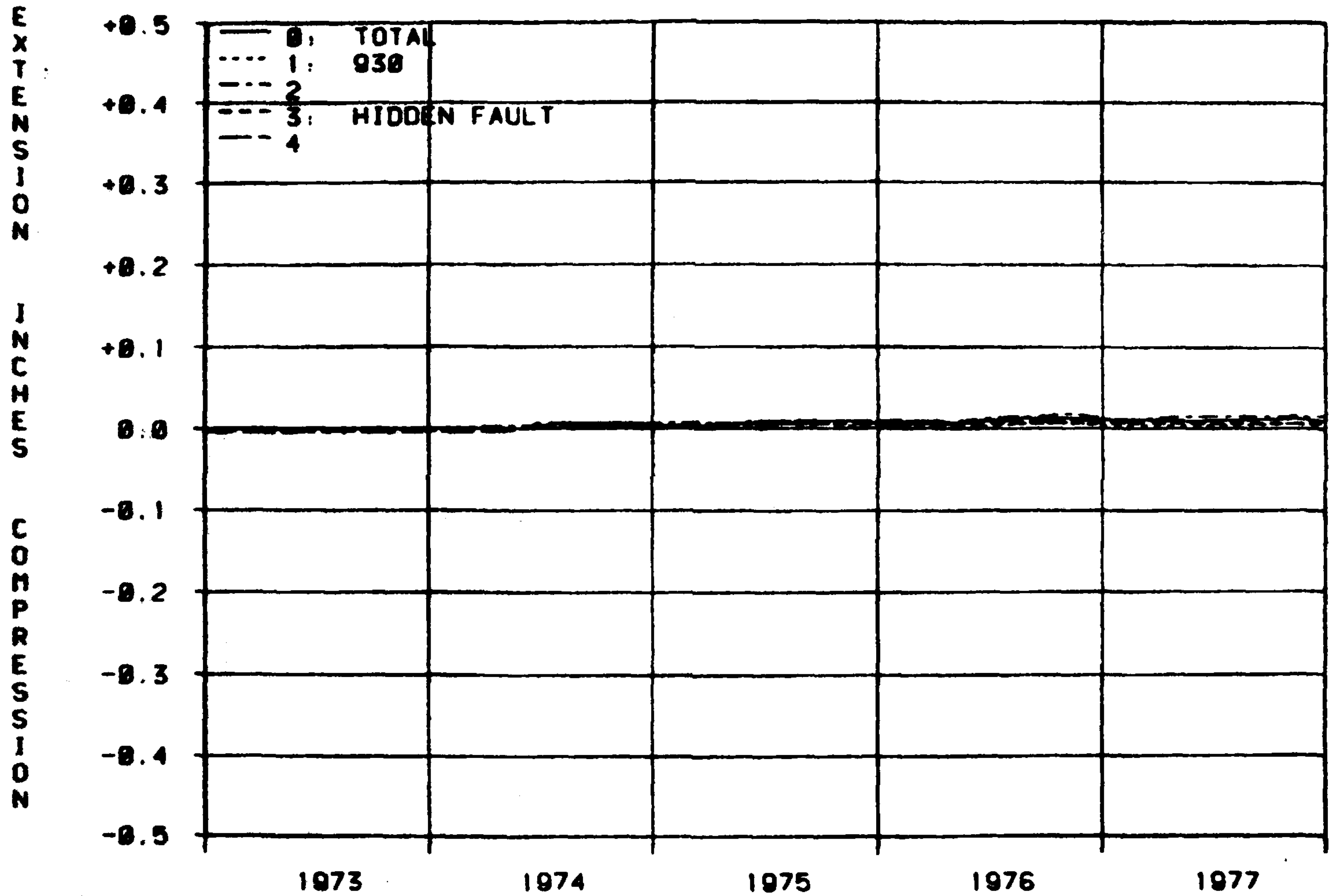
LIBBY LEFT BANK E- 8 (DELTA DISPLACEMENT)



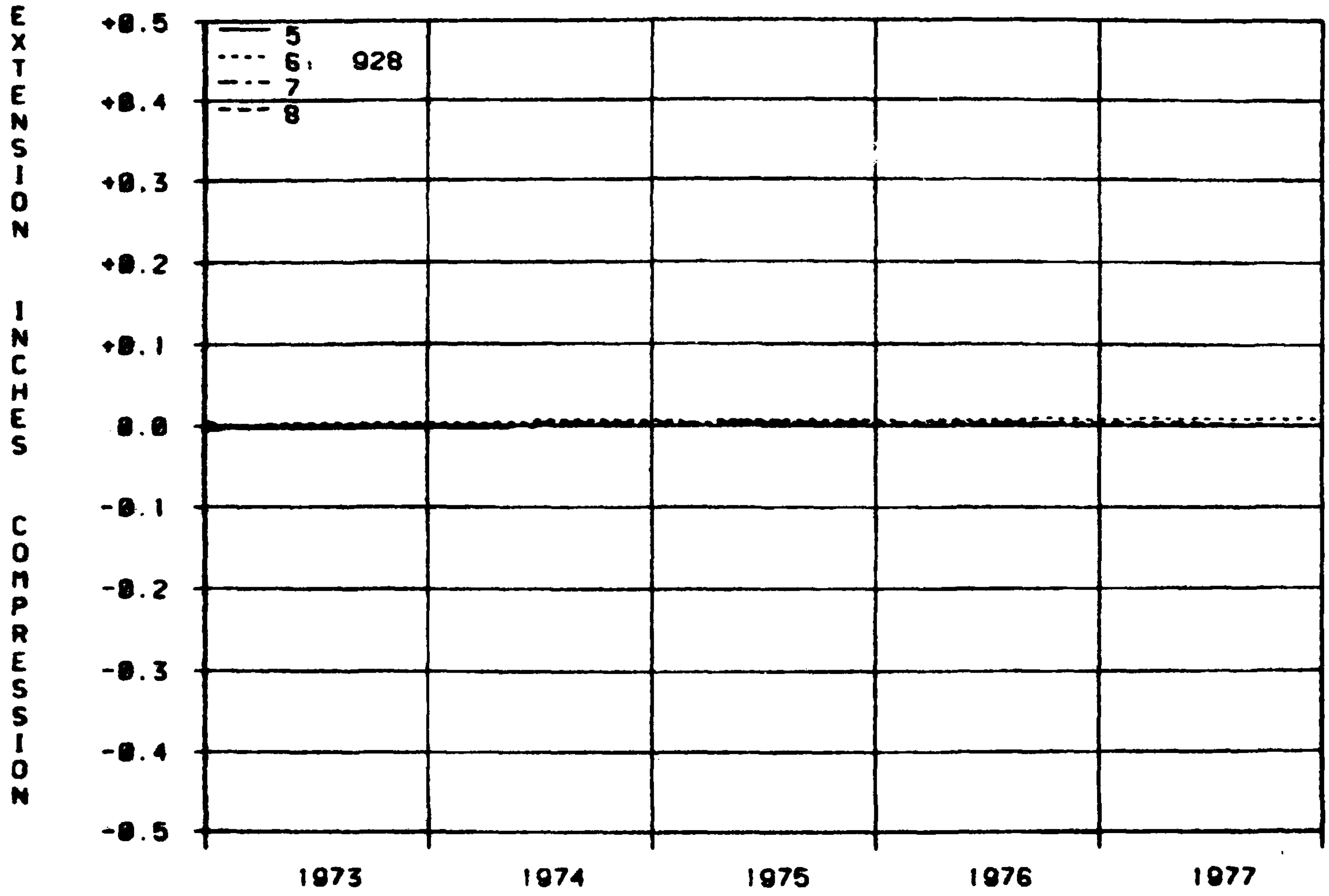
LIBBY LEFT BANK E- 9 (DELTA DISPLACEMENT)



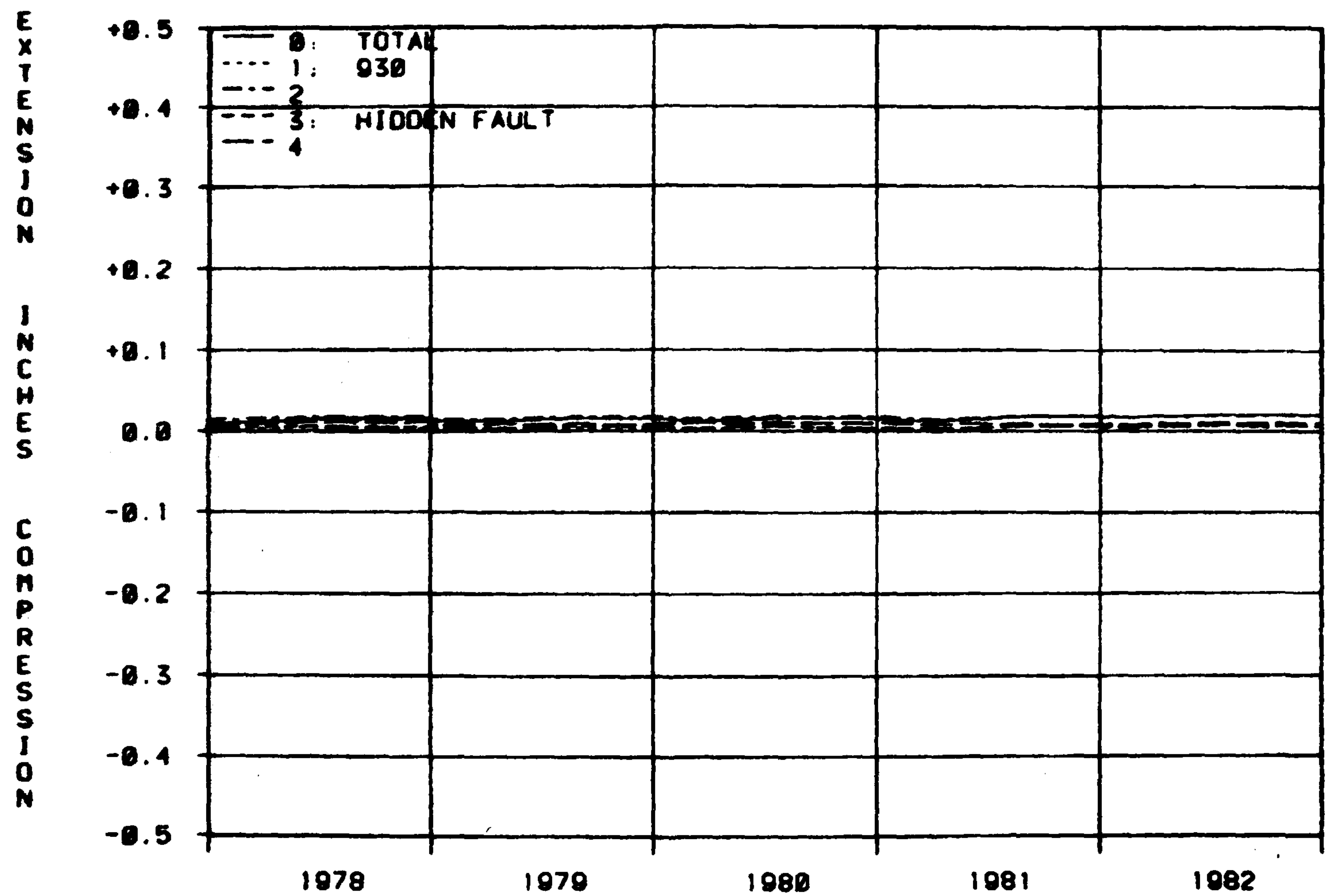
LIBBY LEFT BANK E- 9 (DELTA DISPLACEMENT)



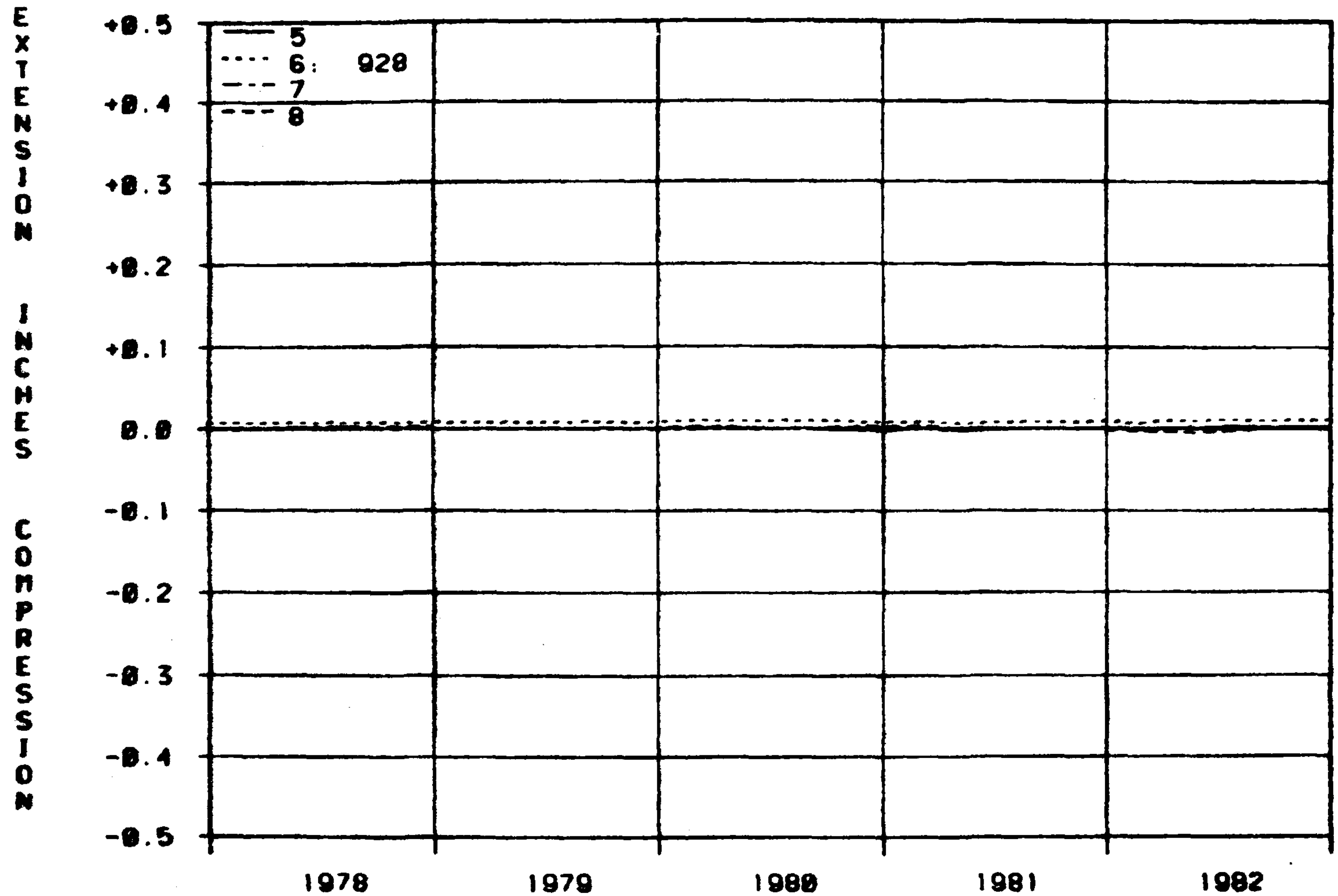
LIBBY LEFT BANK E- 9 (DELTA DISPLACEMENT)



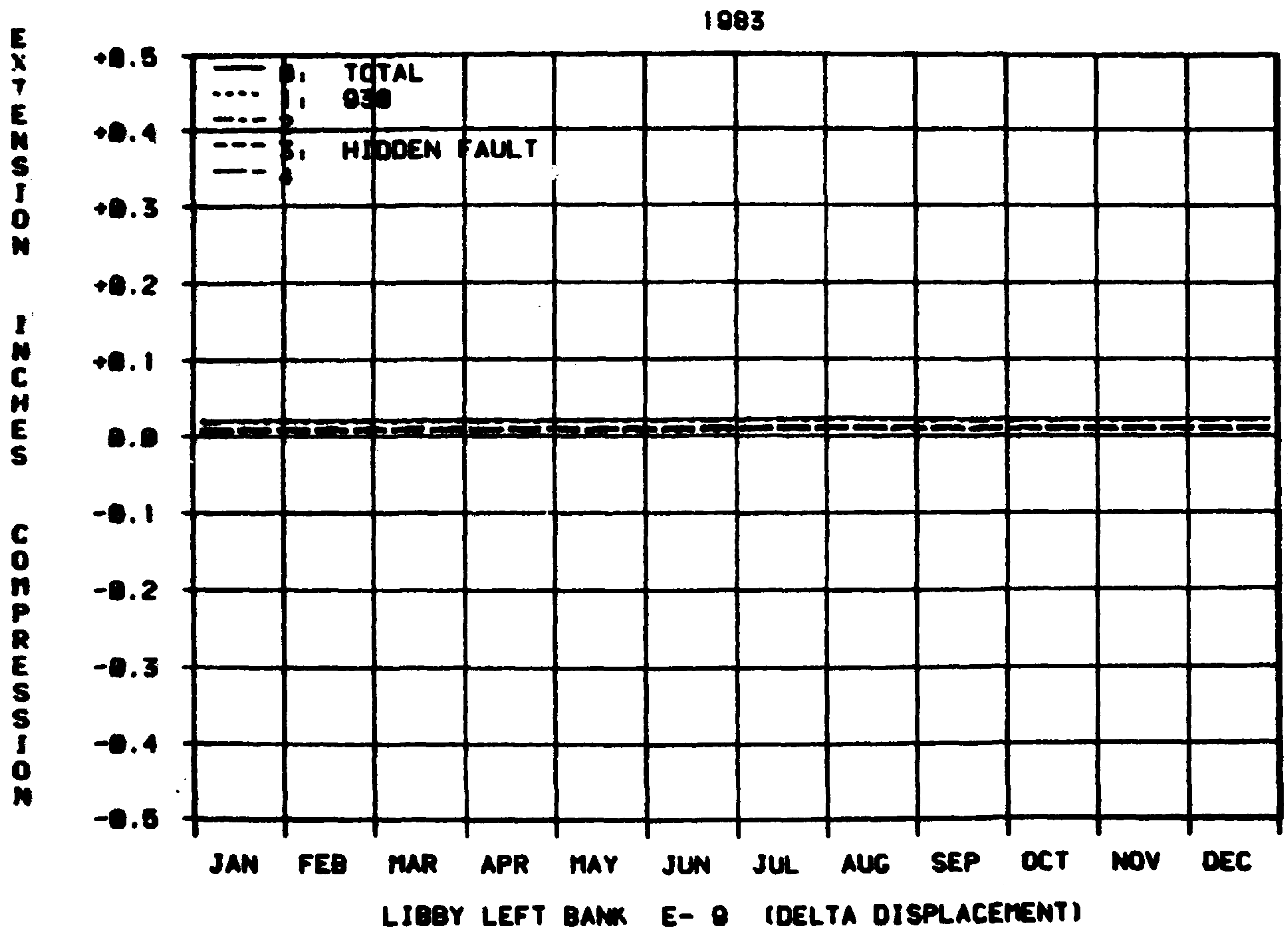
LIBBY LEFT BANK E- 9 (DELTA DISPLACEMENT)

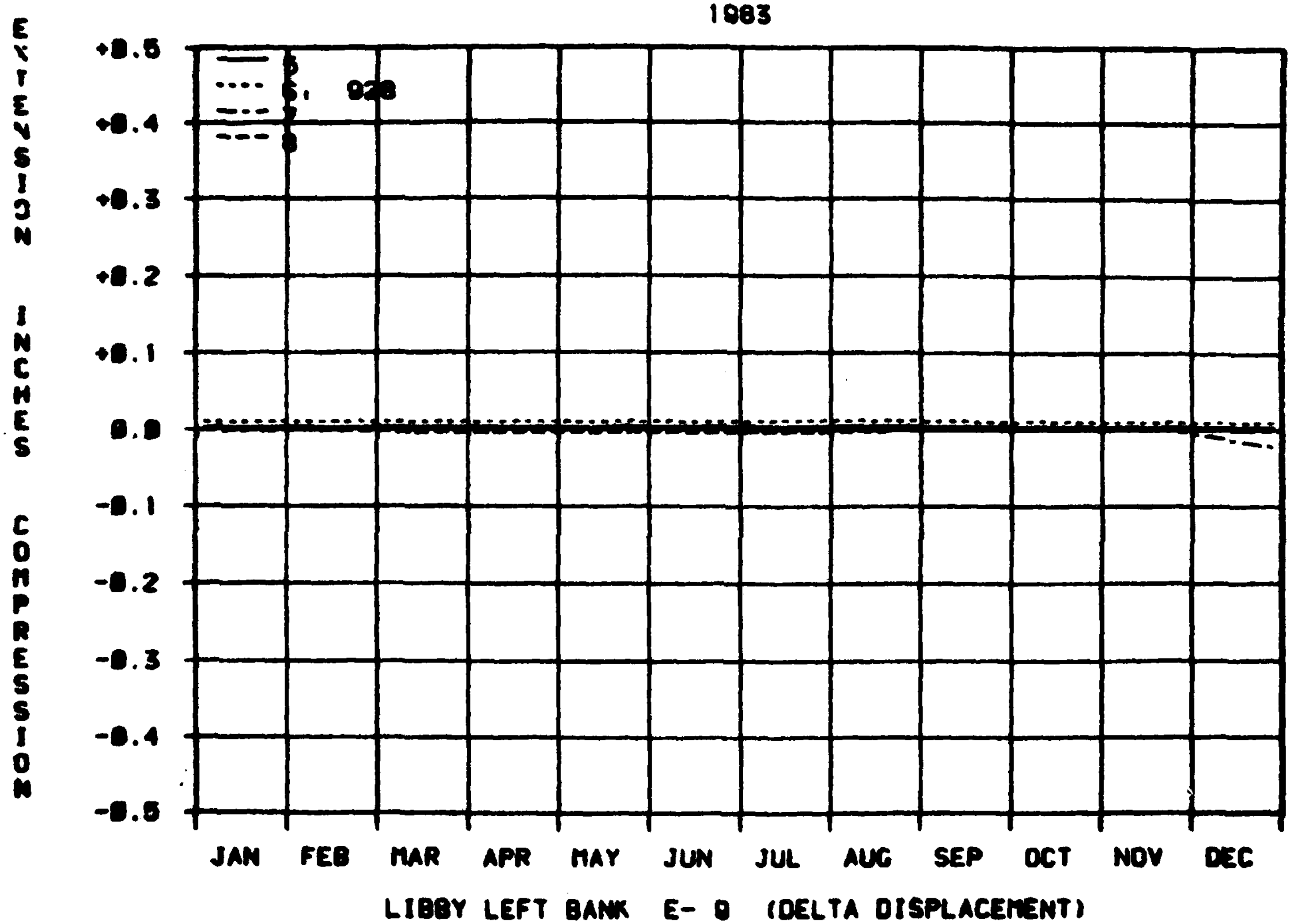


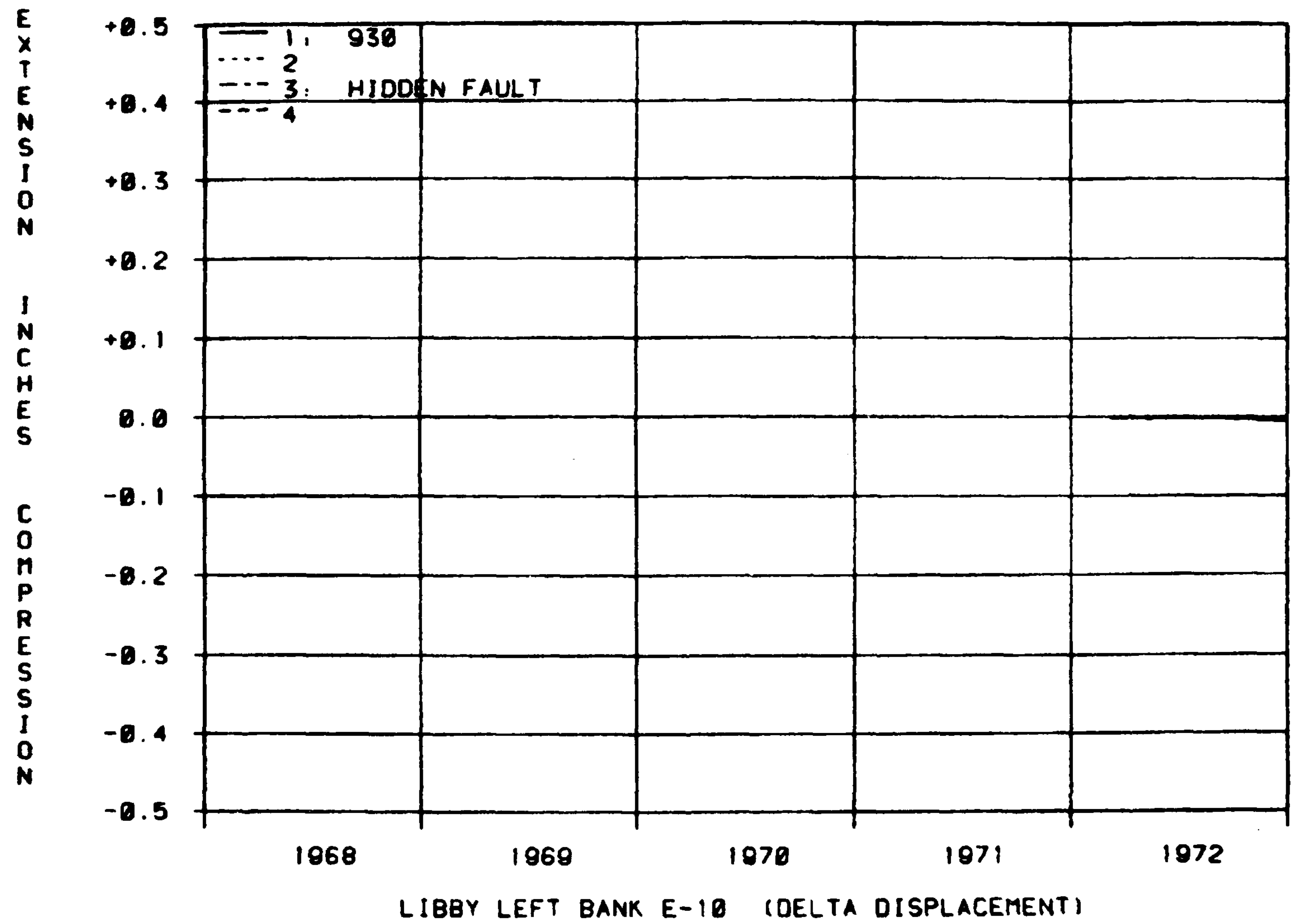
LIBBY LEFT BANK E- 9 (DELTA DISPLACEMENT)

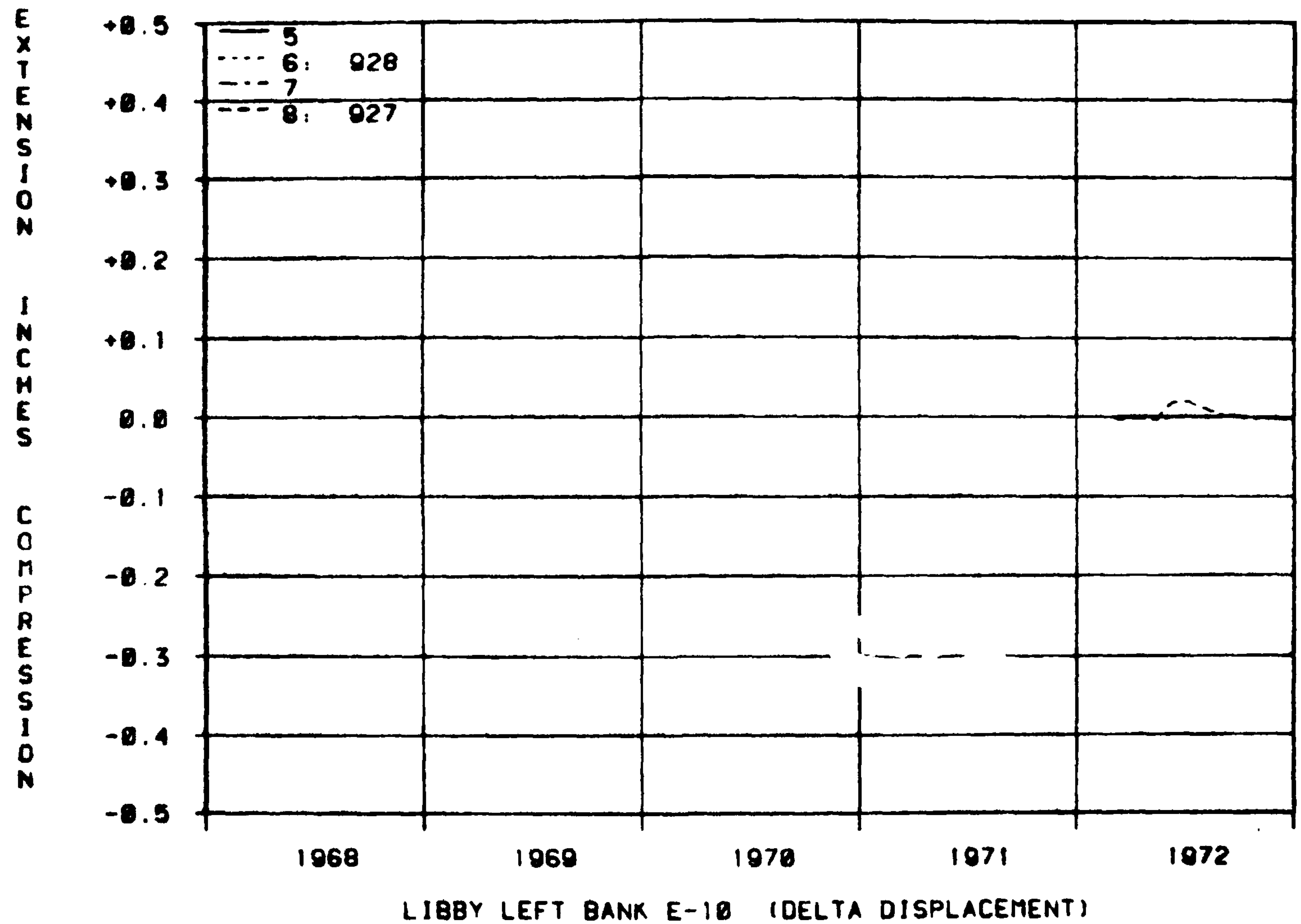


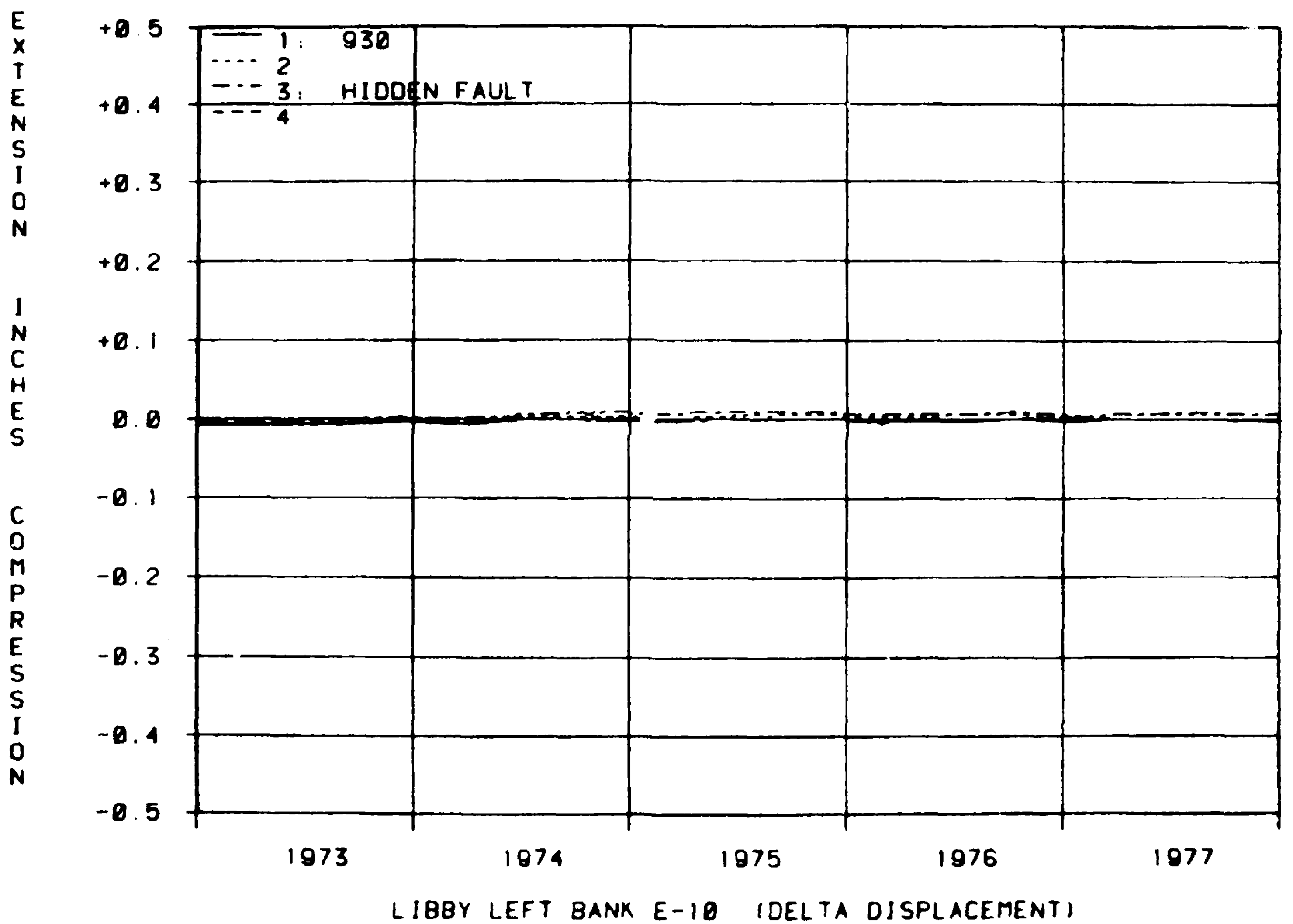
LIBBY LEFT BANK E- 9 (DELTA DISPLACEMENT)

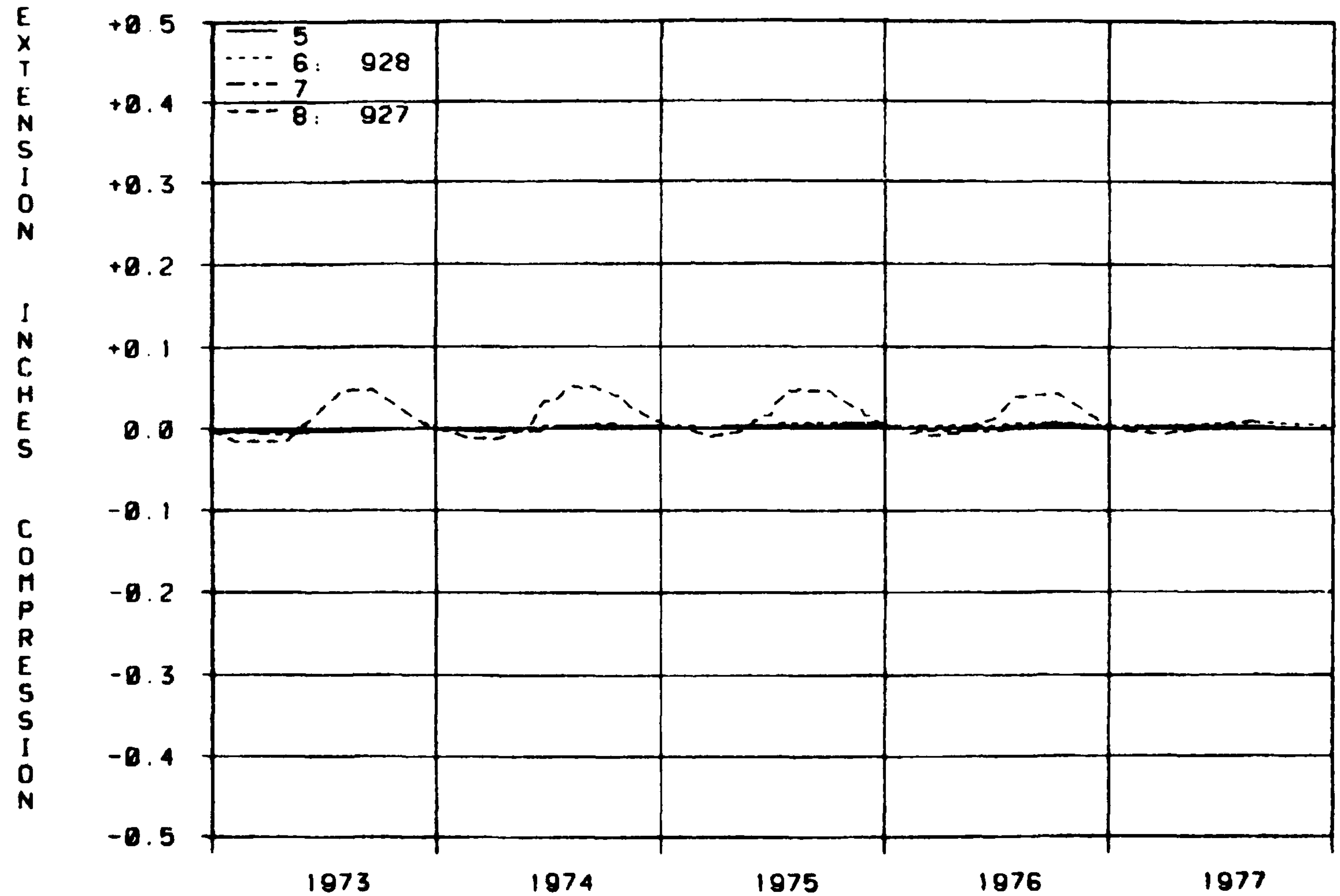

1983
0: TOTAL
1: 938
2
3: HIDDEN FAULT
4
EXTENSION INCHES COMPRESSION
+0.5
+0.4
+0.3
+0.2
+0.1
0.0
-0.1
-0.2
-0.3
-0.4
-0.5
JAN FEB MAR APR MAY JUN JUL AUG SEP OCT NOV DEC
LIBBY LEFT BANK E- 9 (DELTA DISPLACEMENT)


1983
5
6, 928
7
8
EXTENSION INCHES COMPRESSION
+0.5
+0.4
+0.3
+0.2
+0.1
0.0
-0.1
-0.2
-0.3
-0.4
-0.5
JAN FEB MAR APR MAY JUN JUL AUG SEP OCT NOV DEC
LIBBY LEFT BANK E- 9 (DELTA DISPLACEMENT)

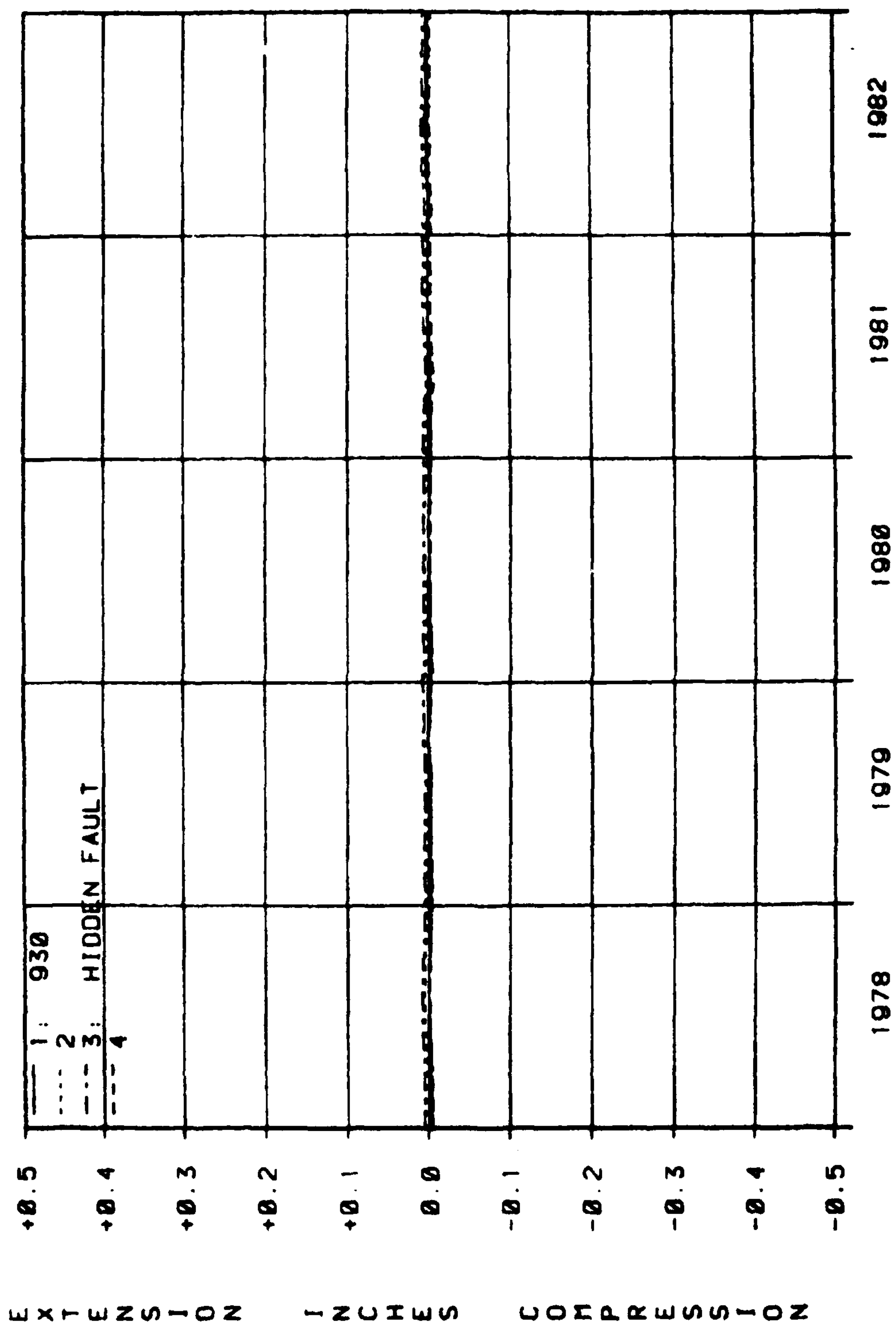

EXTENSION INCHES COMPRESSION
+0.5
+0.4
+0.3
+0.2
+0.1
0.0
-0.1
-0.2
-0.3
-0.4
-0.5
1: 930
2
3: HIDDEN FAULT
4
1968
1969
1970
1971
1972
LIBBY LEFT BANK E-10 (DELTA DISPLACEMENT)


EXTENSION INCHES COMPRESSION
+0.5
+0.4
+0.3
+0.2
+0.1
0.0
-0.1
-0.2
-0.3
-0.4
-0.5
5
6: 928
7
8: 927
1968
1969
1970
1971
1972
LIBBY LEFT BANK E-10 (DELTA DISPLACEMENT)

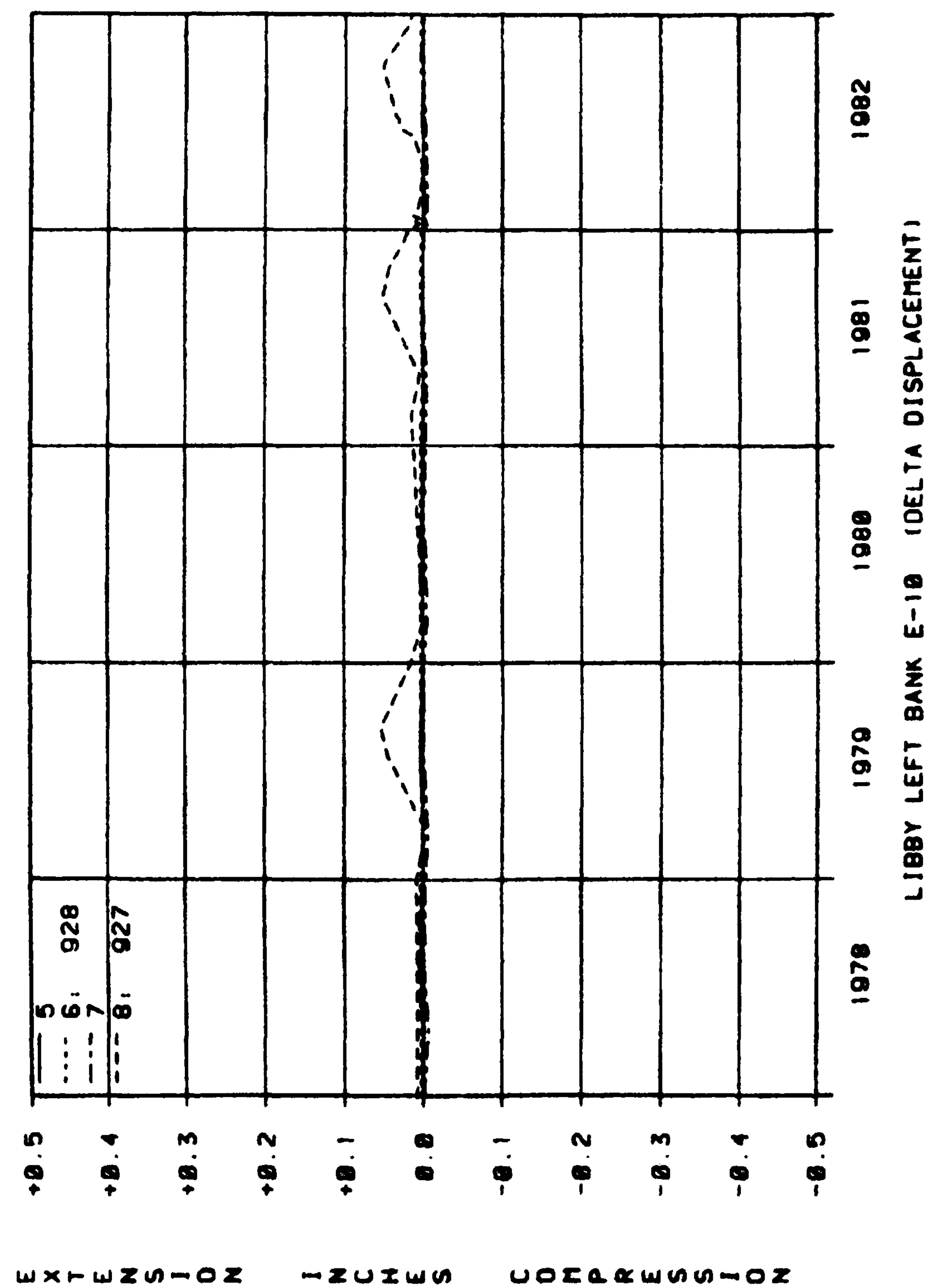

EXTENSION INCHES COMPRESSION
+0.5
+0.4
+0.3
+0.2
+0.1
0.0
-0.1
-0.2
-0.3
-0.4
-0.5
1: 930
2
3: HIDDEN FAULT
4
1973
1974
1975
1976
1977
LIBBY LEFT BANK E-10 (DELTA DISPLACEMENT)

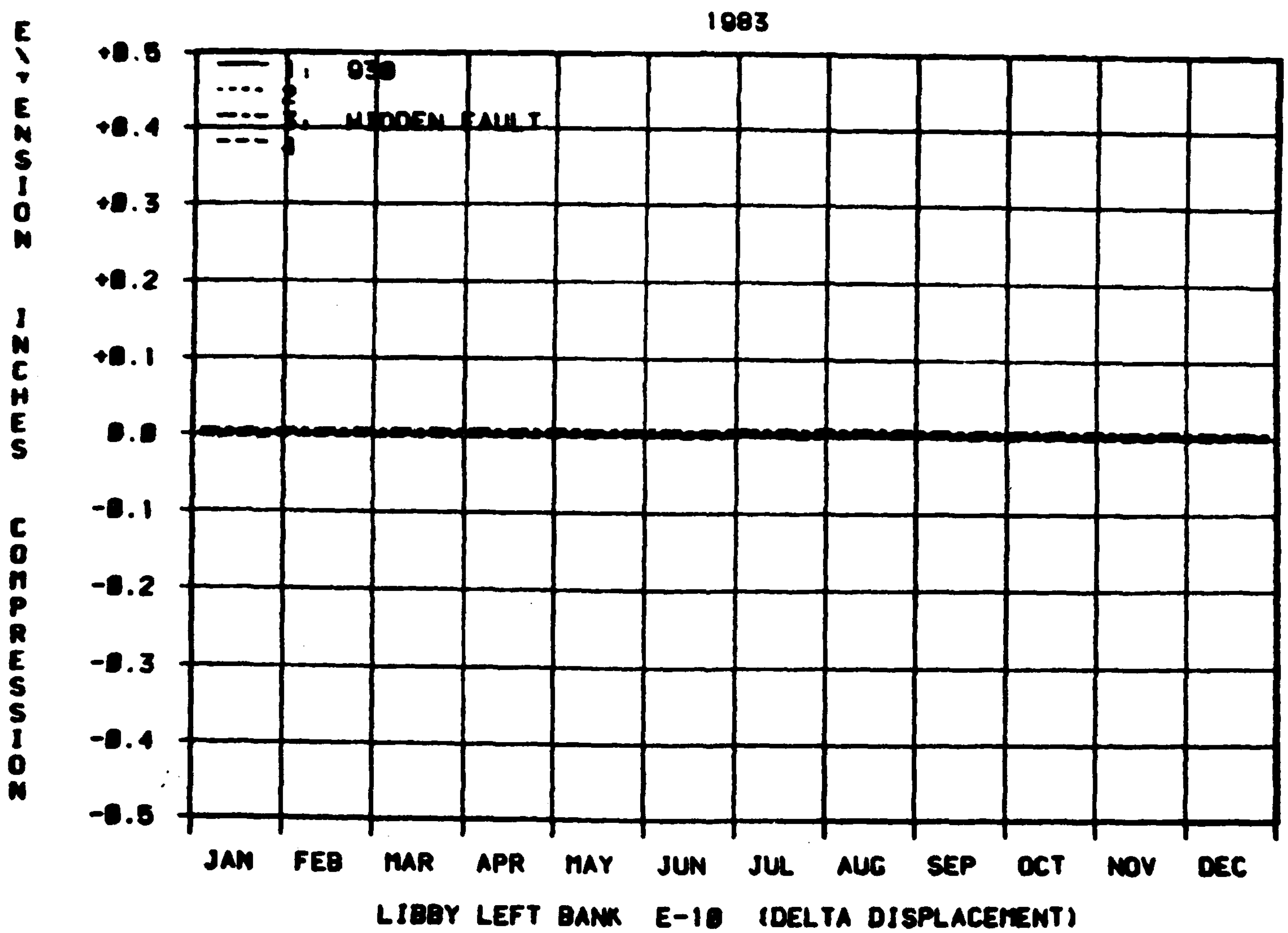


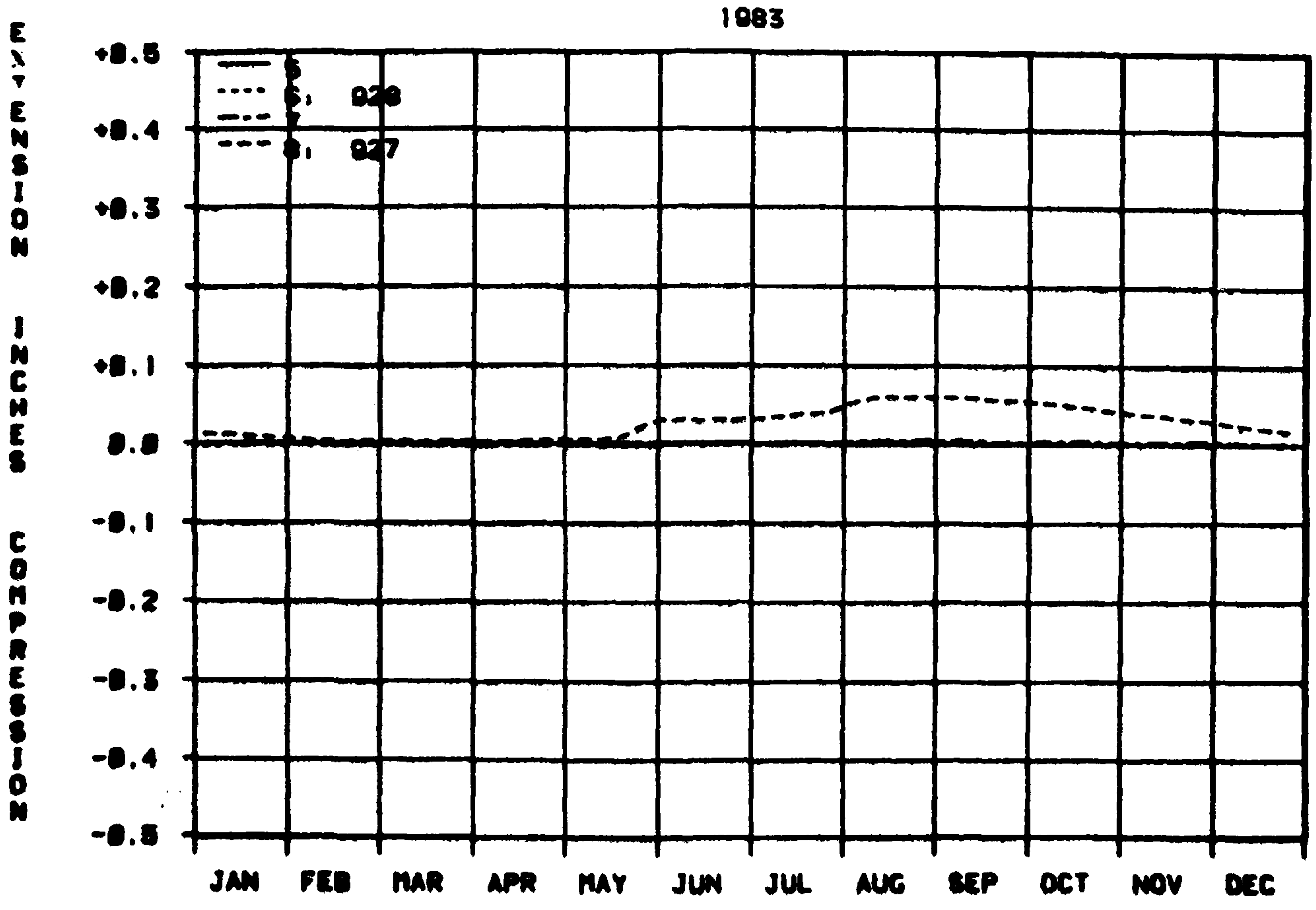
LIBBY LEFT BANK E-10 (DELTA DISPLACEMENT)



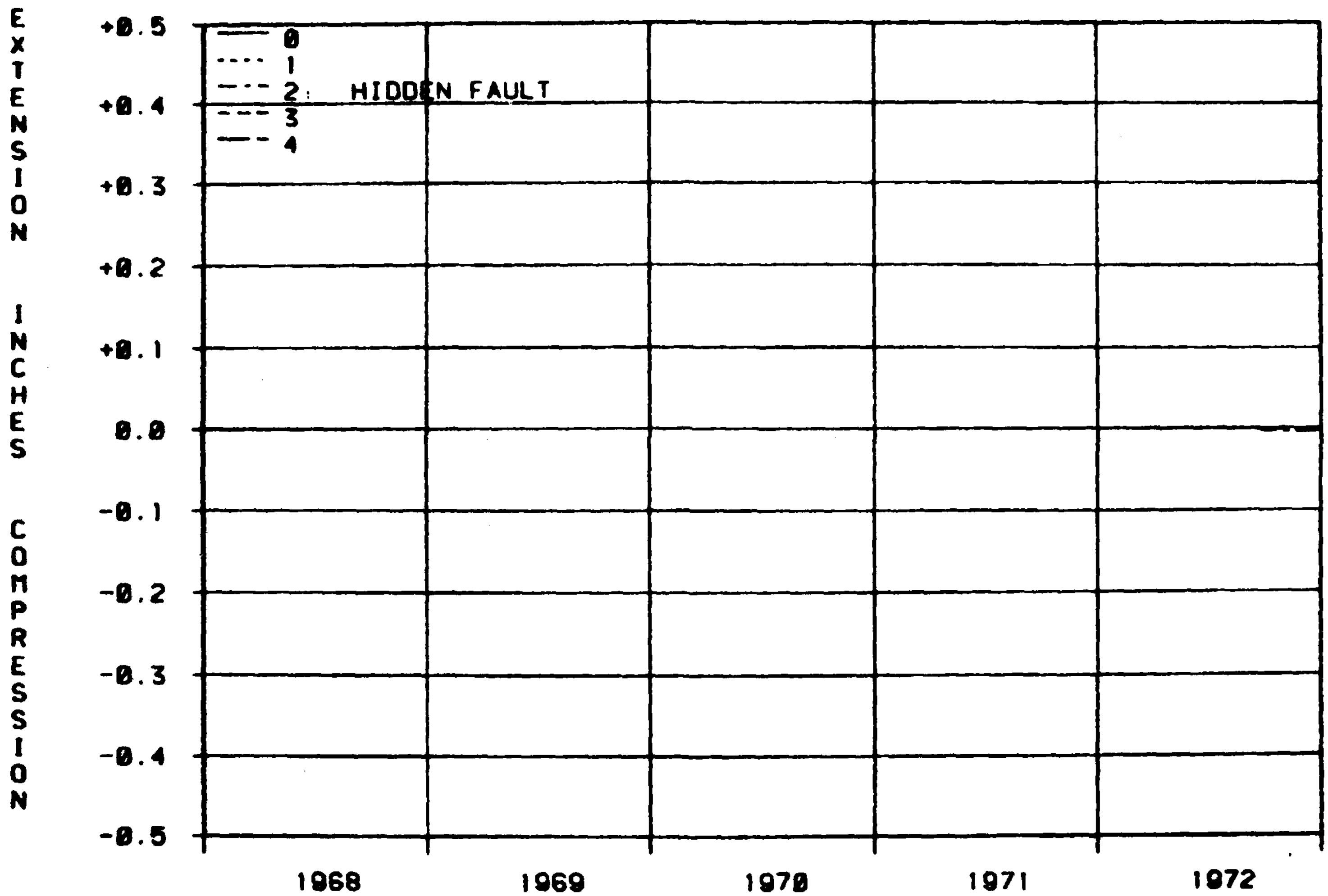
LIBBY LEFT BANK E-10 (DELTA DISPLACEMENT)


LIBBY LEFT BANK E-10 (DELTA DISPLACEMENT)
EXTENSION INCHES COMPRESSION
+0.5
+0.4
+0.3
+0.2
+0.1
0.0
-0.1
-0.2
-0.3
-0.4
-0.5
1978
1979
1980
1981
1982
5
6: 928
7
8: 927

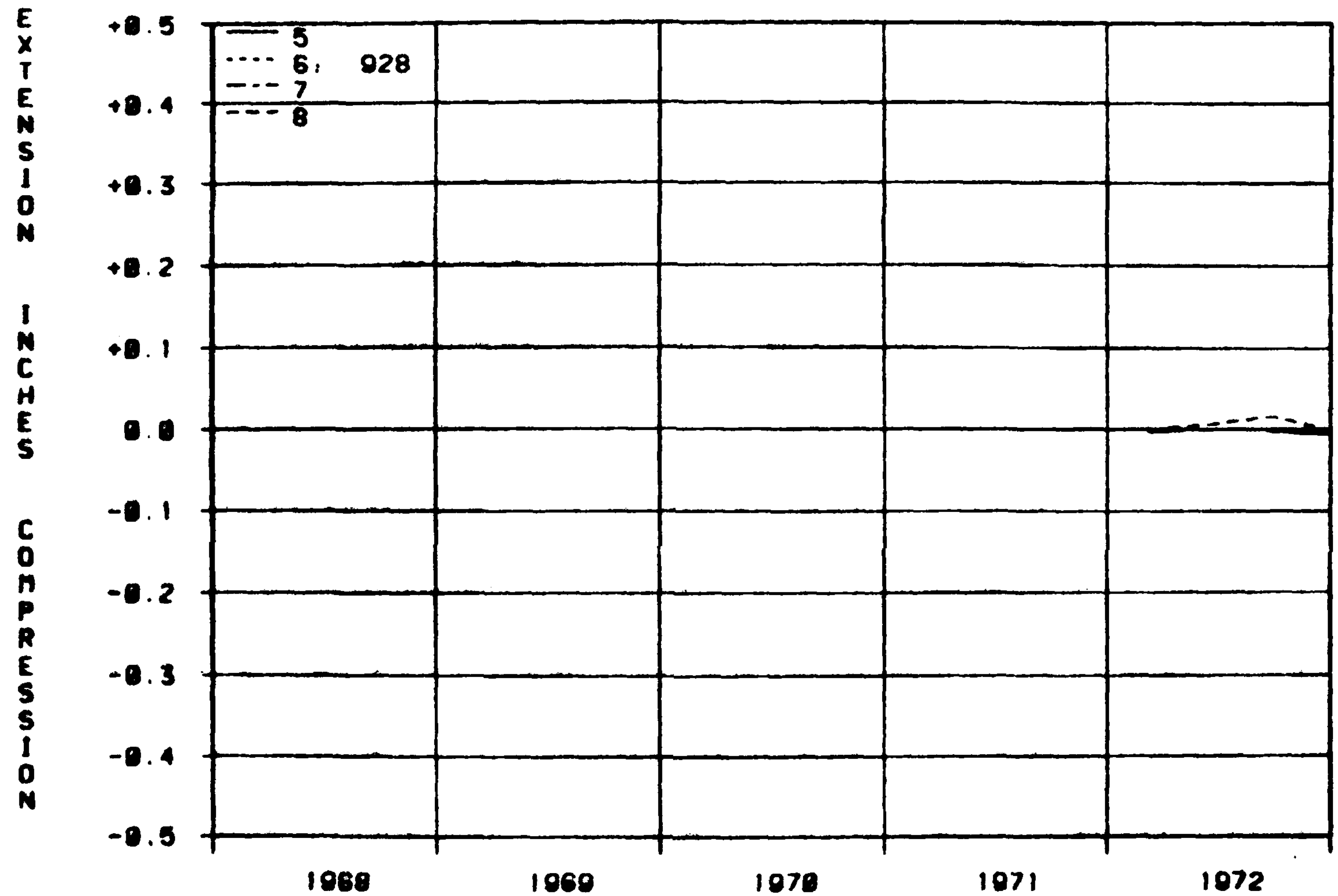

1983
1: 93B
2
3: HIDDEN FAULT
4
EXTENSION INCHES COMPRESSION
+0.5
+0.4
+0.3
+0.2
+0.1
0.0
-0.1
-0.2
-0.3
-0.4
-0.5
JAN FEB MAR APR MAY JUN JUL AUG SEP OCT NOV DEC
LIBBY LEFT BANK E-10 (DELTA DISPLACEMENT)



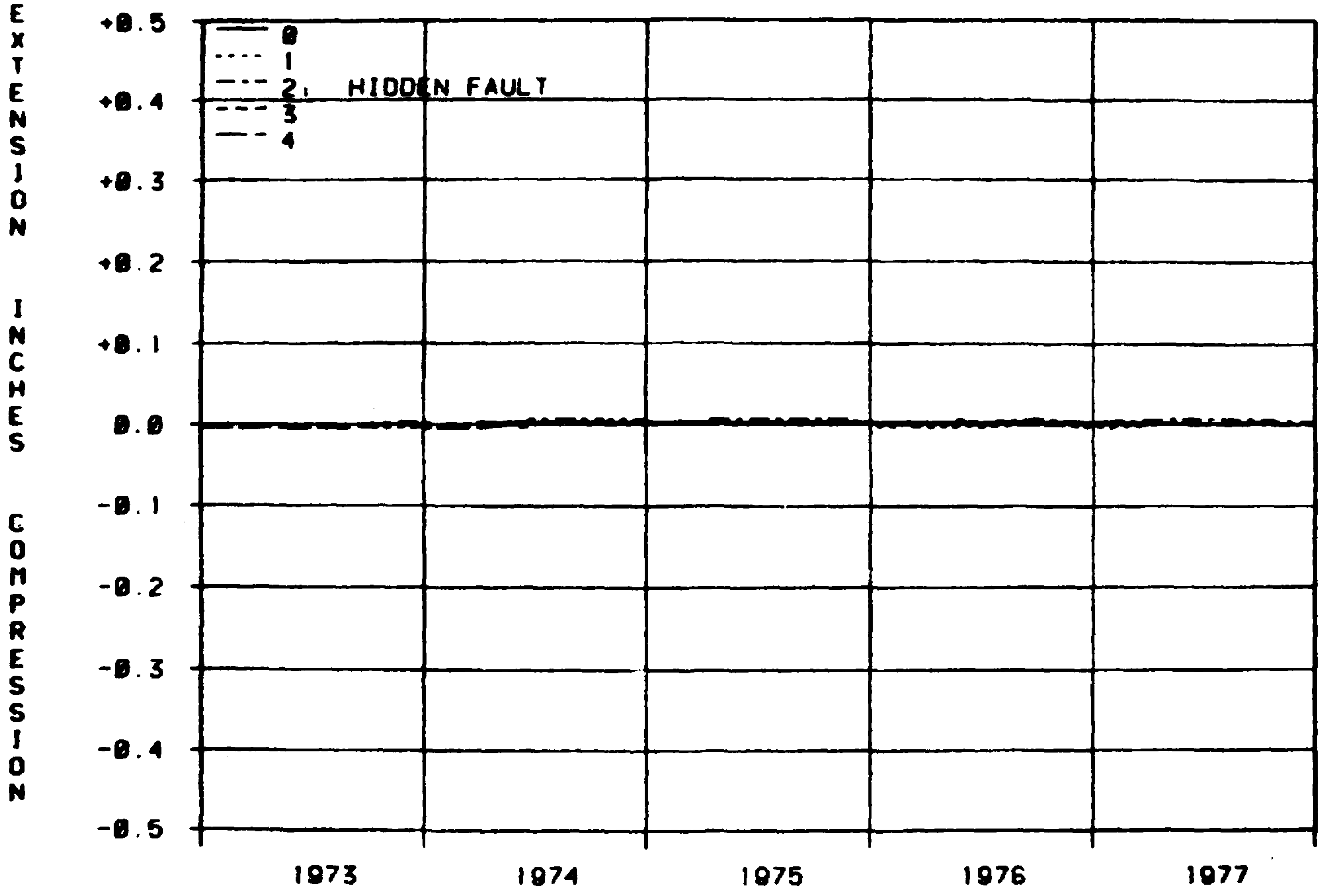
LIBBY LEFT BANK E-10 (DELTA DISPLACEMENT)



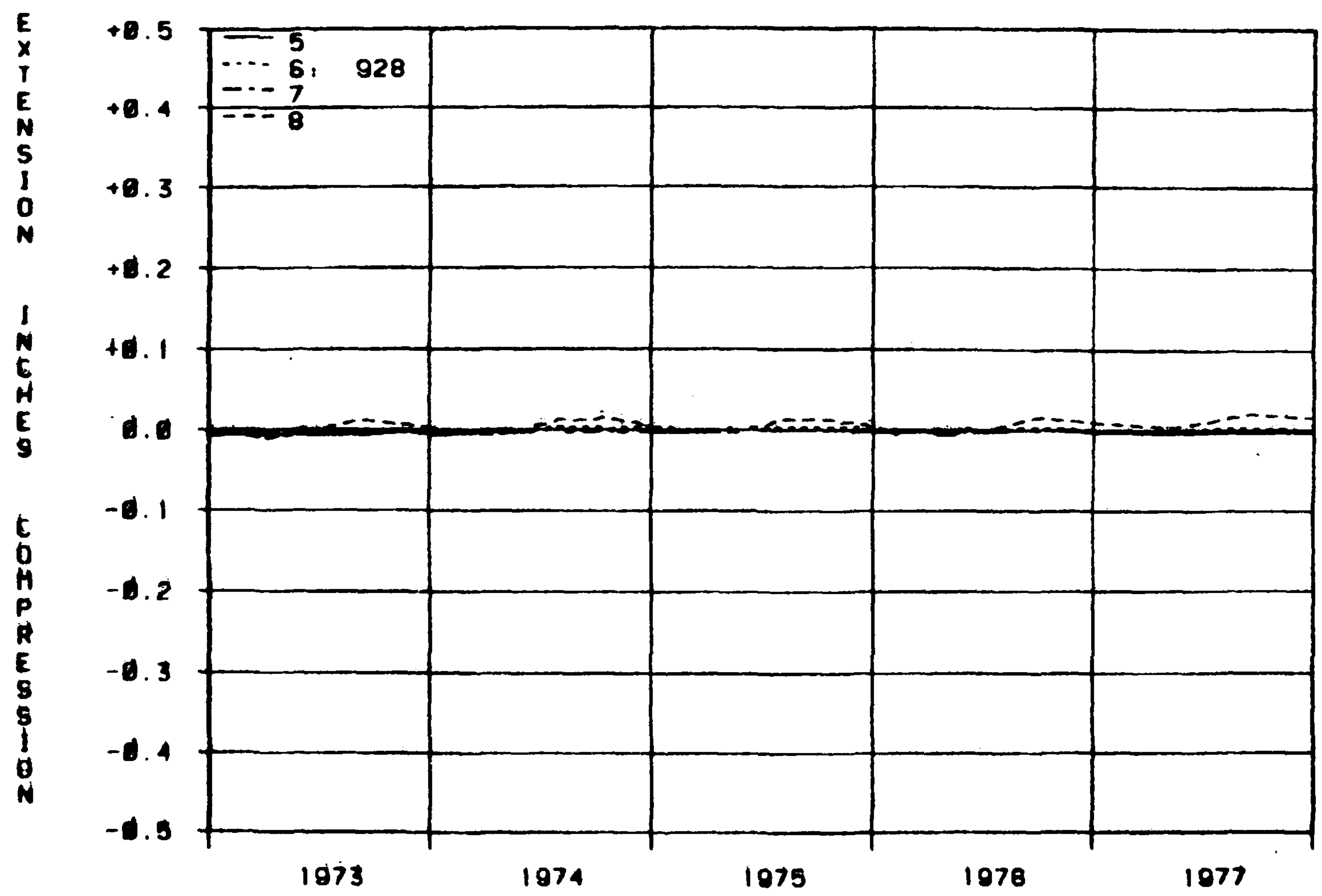
LIBBY LEFT BANK E-11 (DELTA DISPLACEMENT)



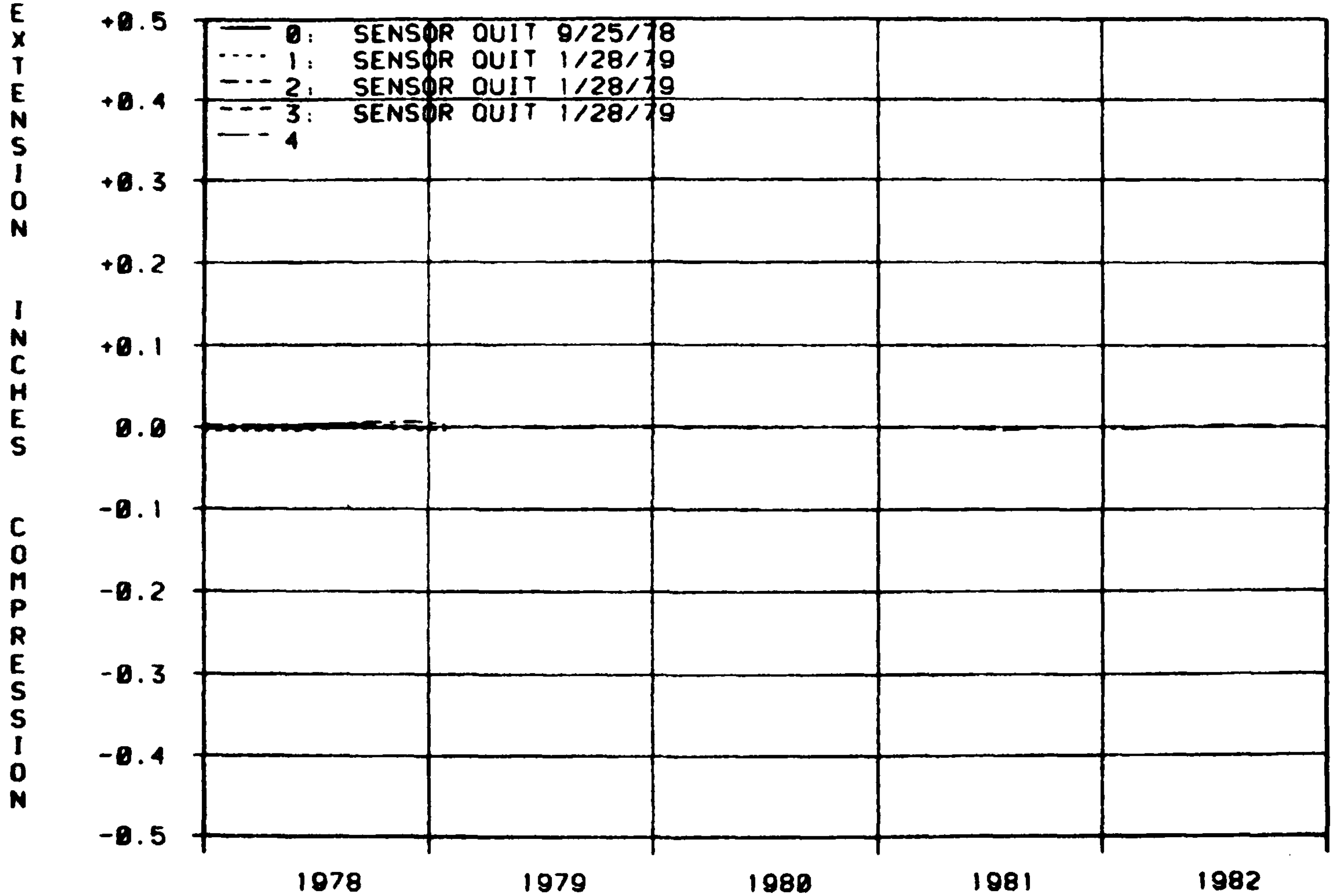
LIBBY LEFT BANK E-11 (DELTA DISPLACEMENT)



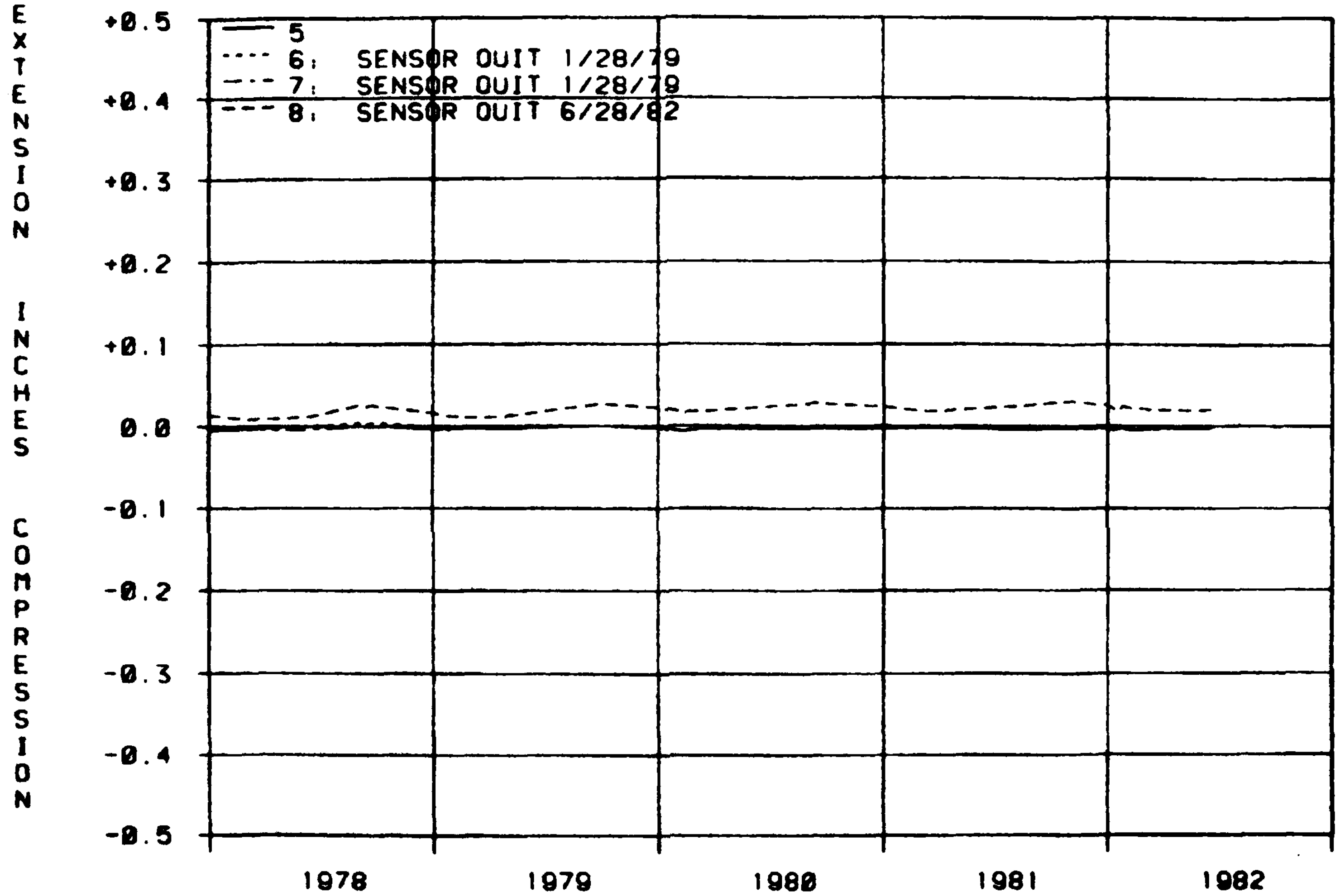
LIBBY LEFT BANK E-11 (DELTA DISPLACEMENT)



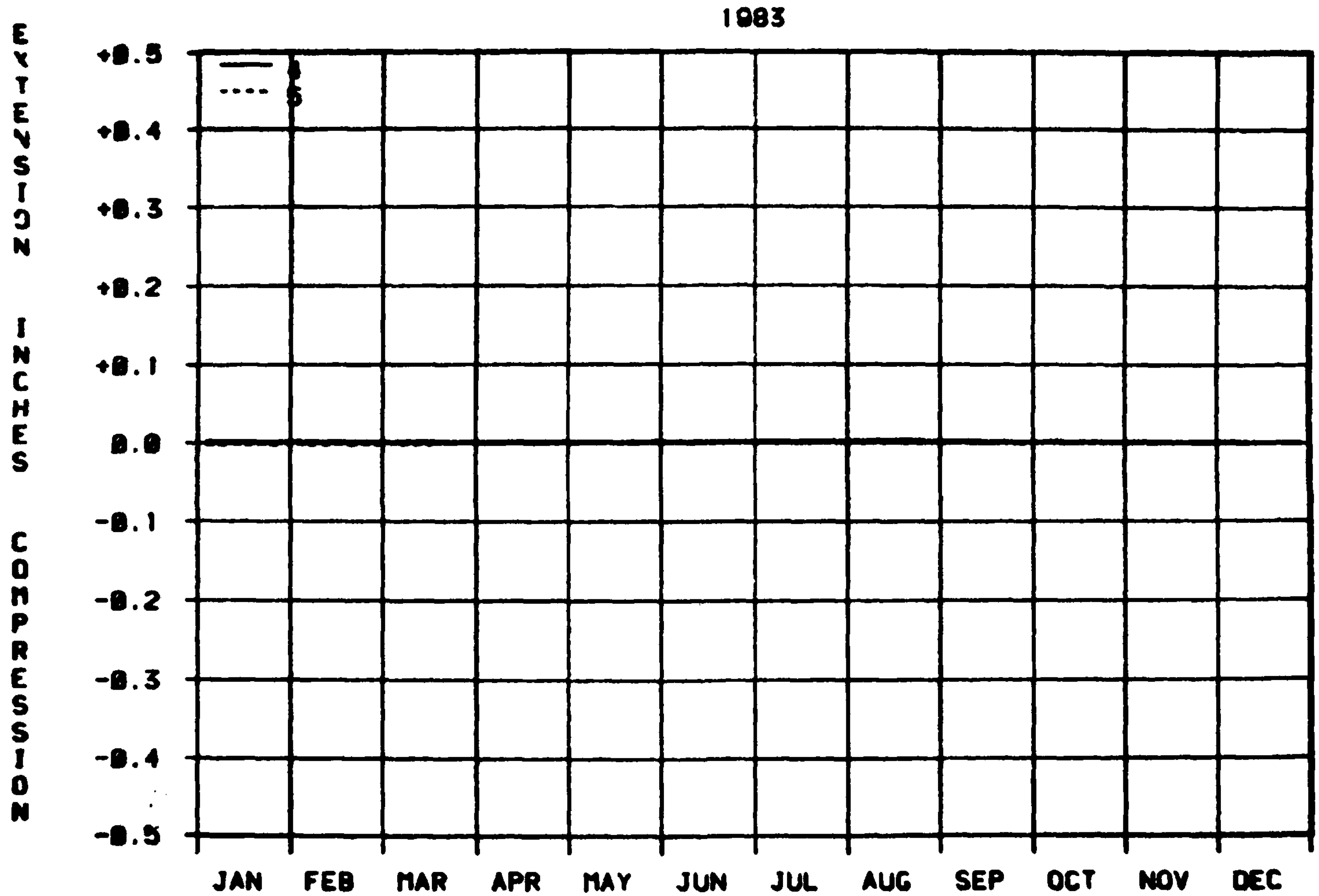
LIBBY LEFT BANK E-11 (DELTA DISPLACEMENT)



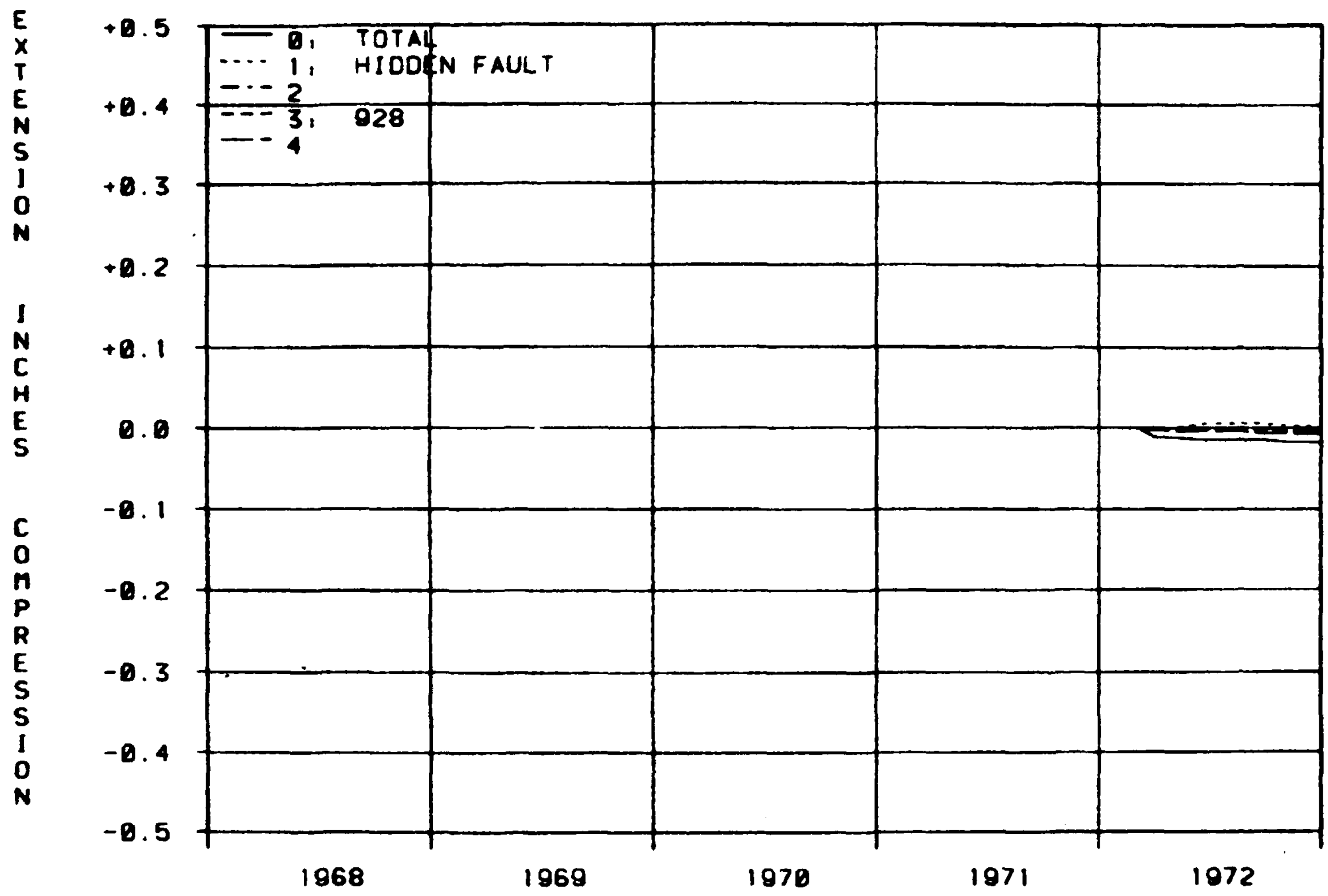
LIBBY LEFT BANK E-11 (DELTA DISPLACEMENT)



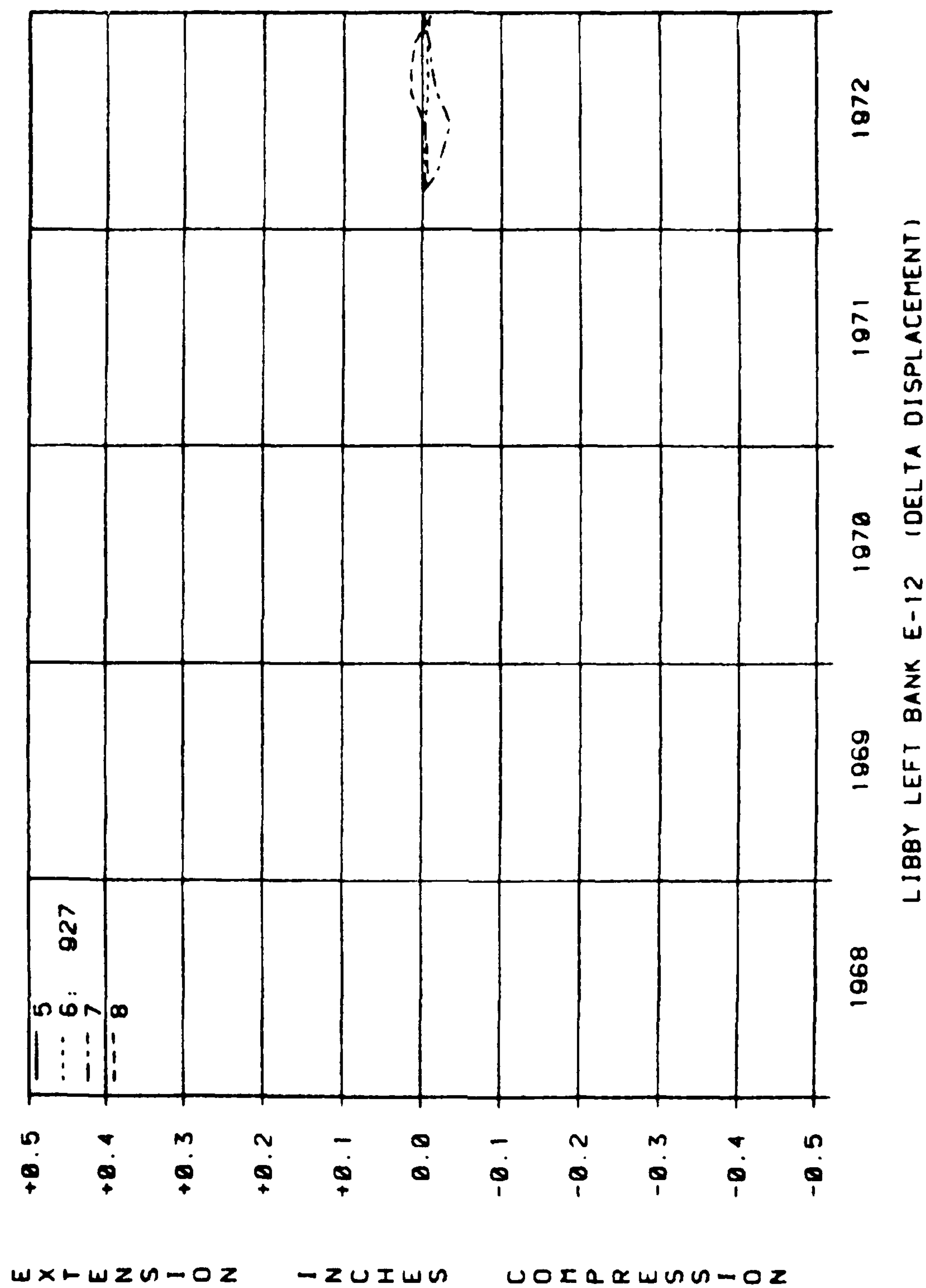
LIBBY LEFT BANK E-11 (DELTA DISPLACEMENT)

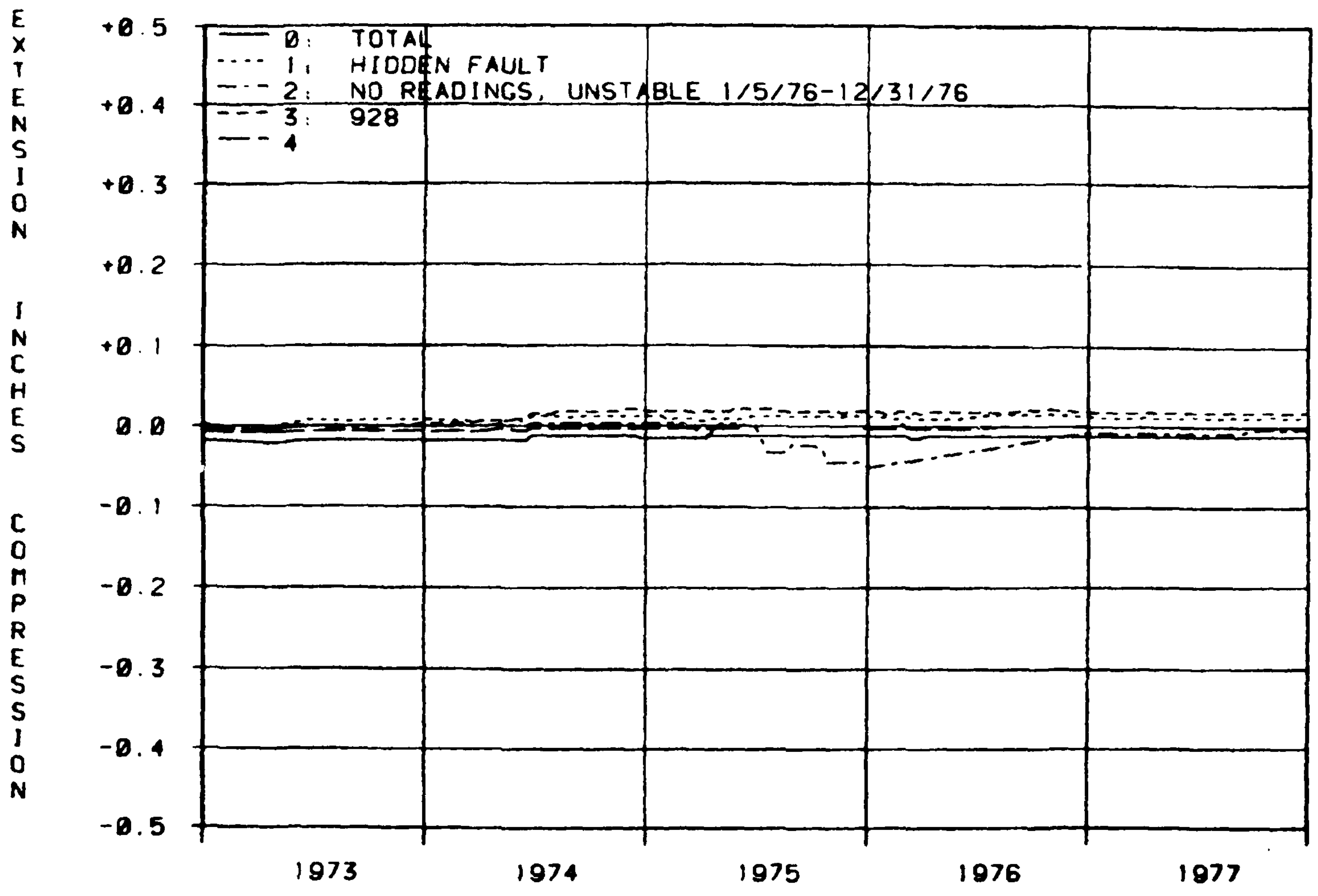


LIBBY LEFT BANK E-11 (DELTA DISPLACEMENT)

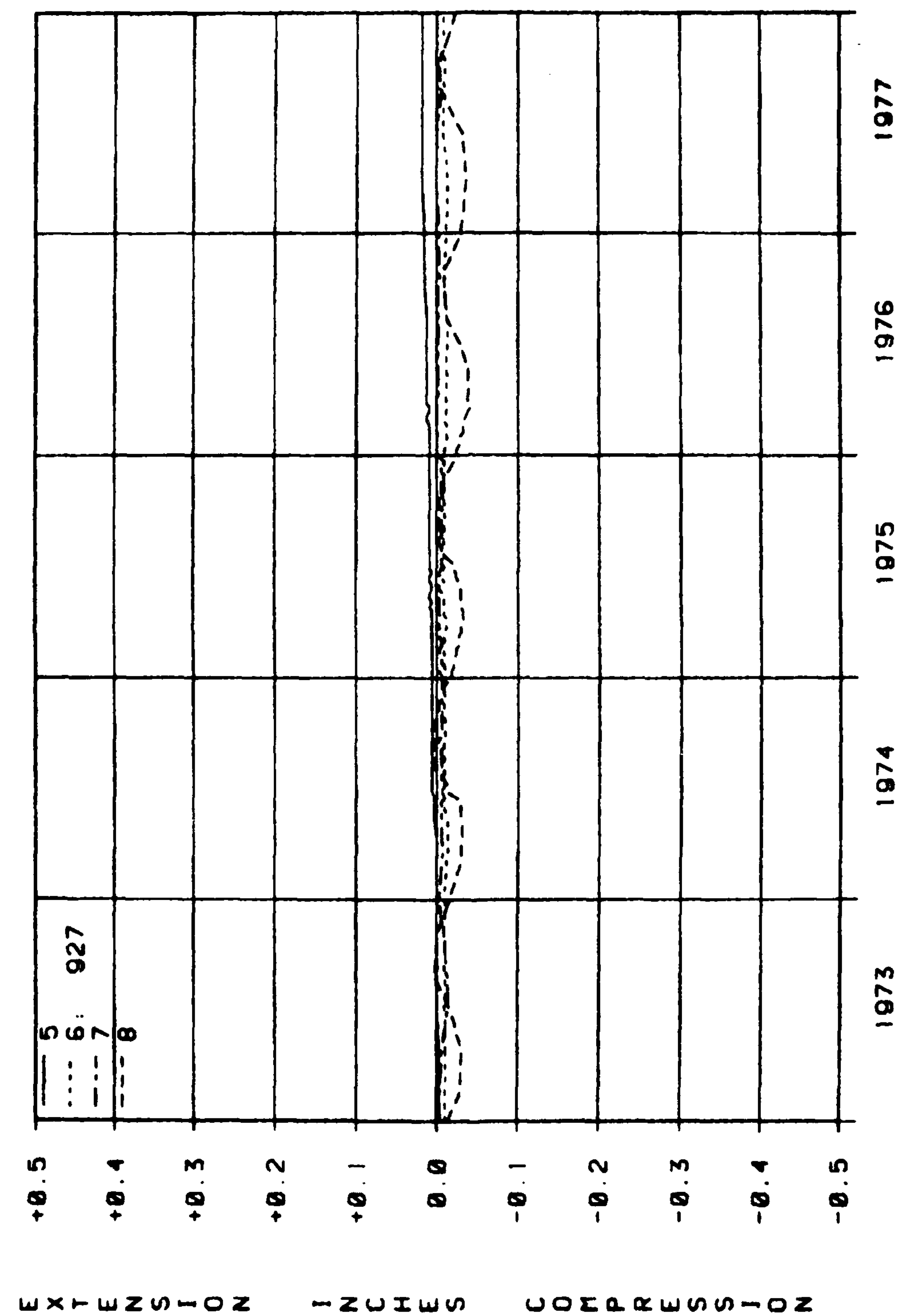


LIBBY LEFT BANK E-12 (DELTA DISPLACEMENT)

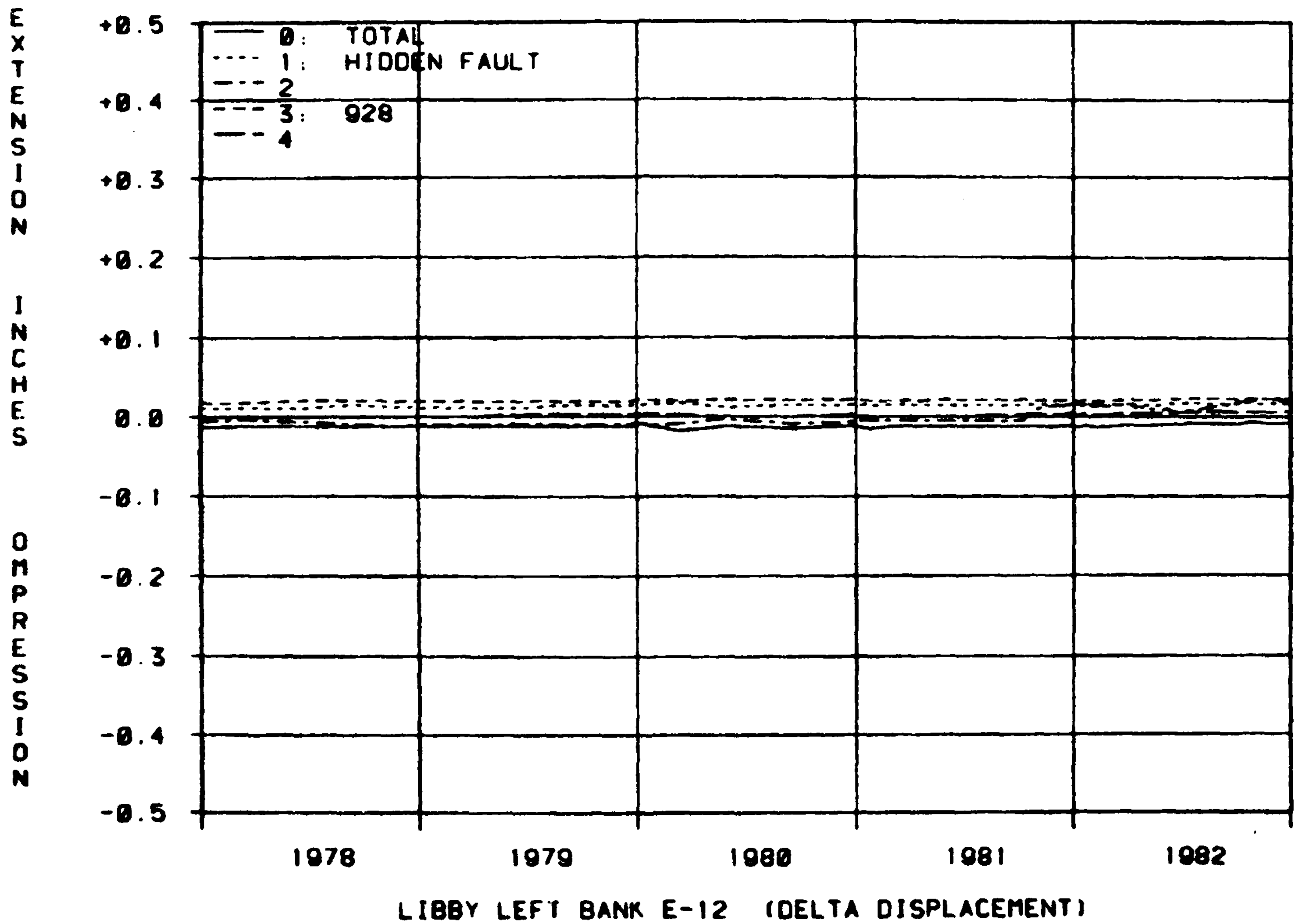

5
6
7
8
927
1968
1969
1970
1971
1972
LIBBY LEFT BANK E-12 (DELTA DISPLACEMENT)
+0.5
+0.4
+0.3
+0.2
+0.1
0.0
-0.1
-0.2
-0.3
-0.4
-0.5
EXTENSION INCHES COMPRESSION



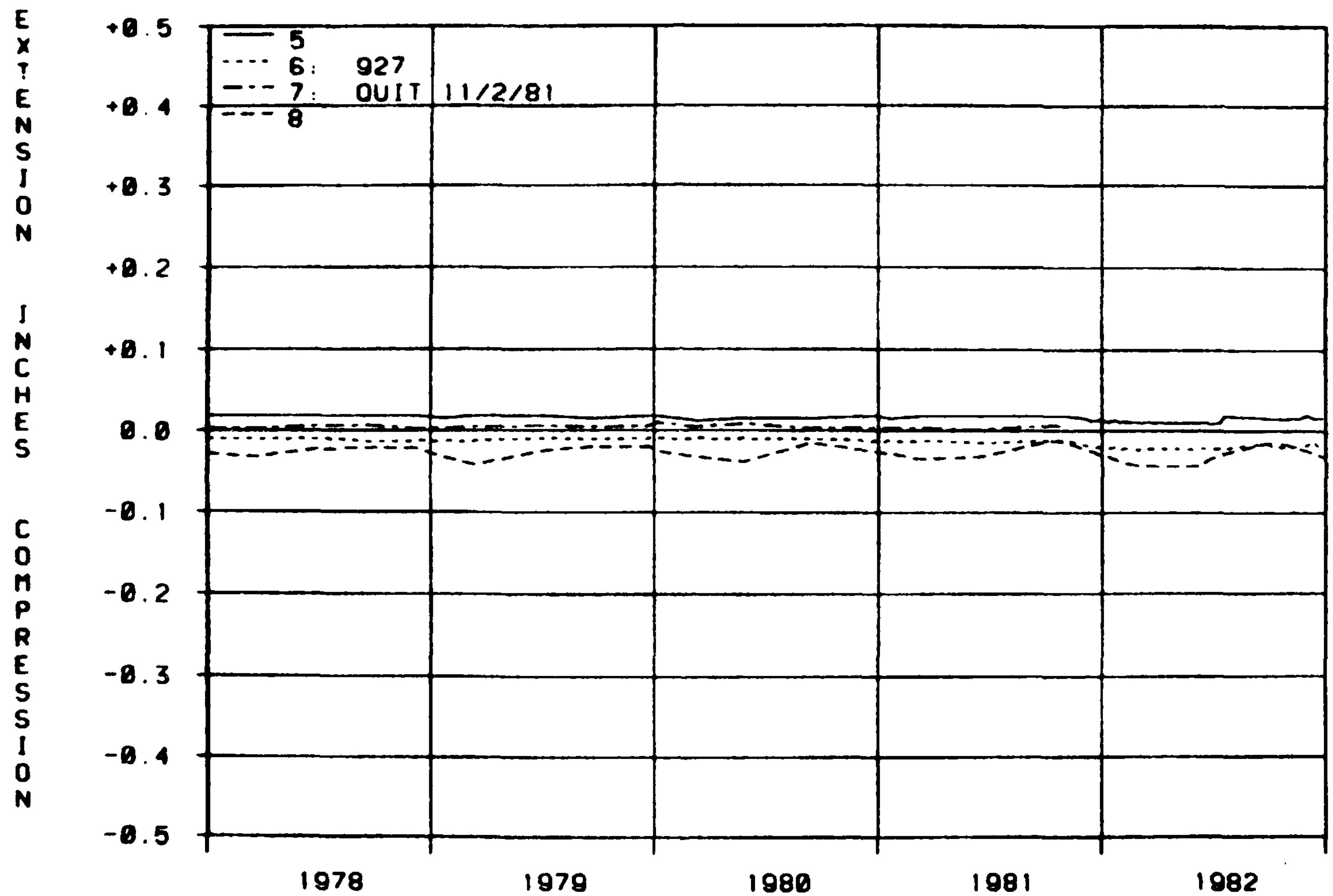
LIBBY LEFT BANK E-12 (DELTA DISPLACEMENT)



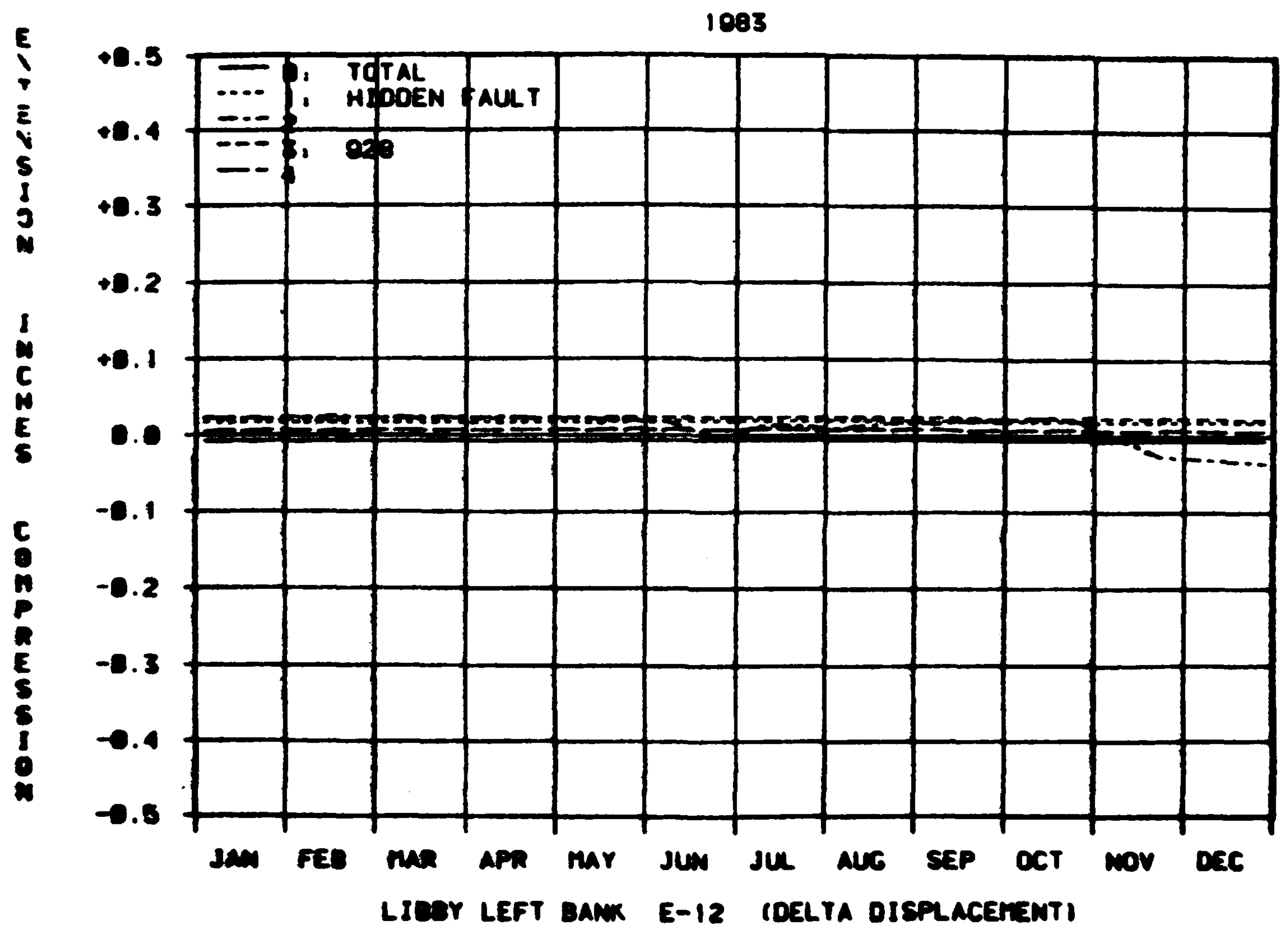
LIBBY LEFT BANK E-12 (DELTA DISPLACEMENT)

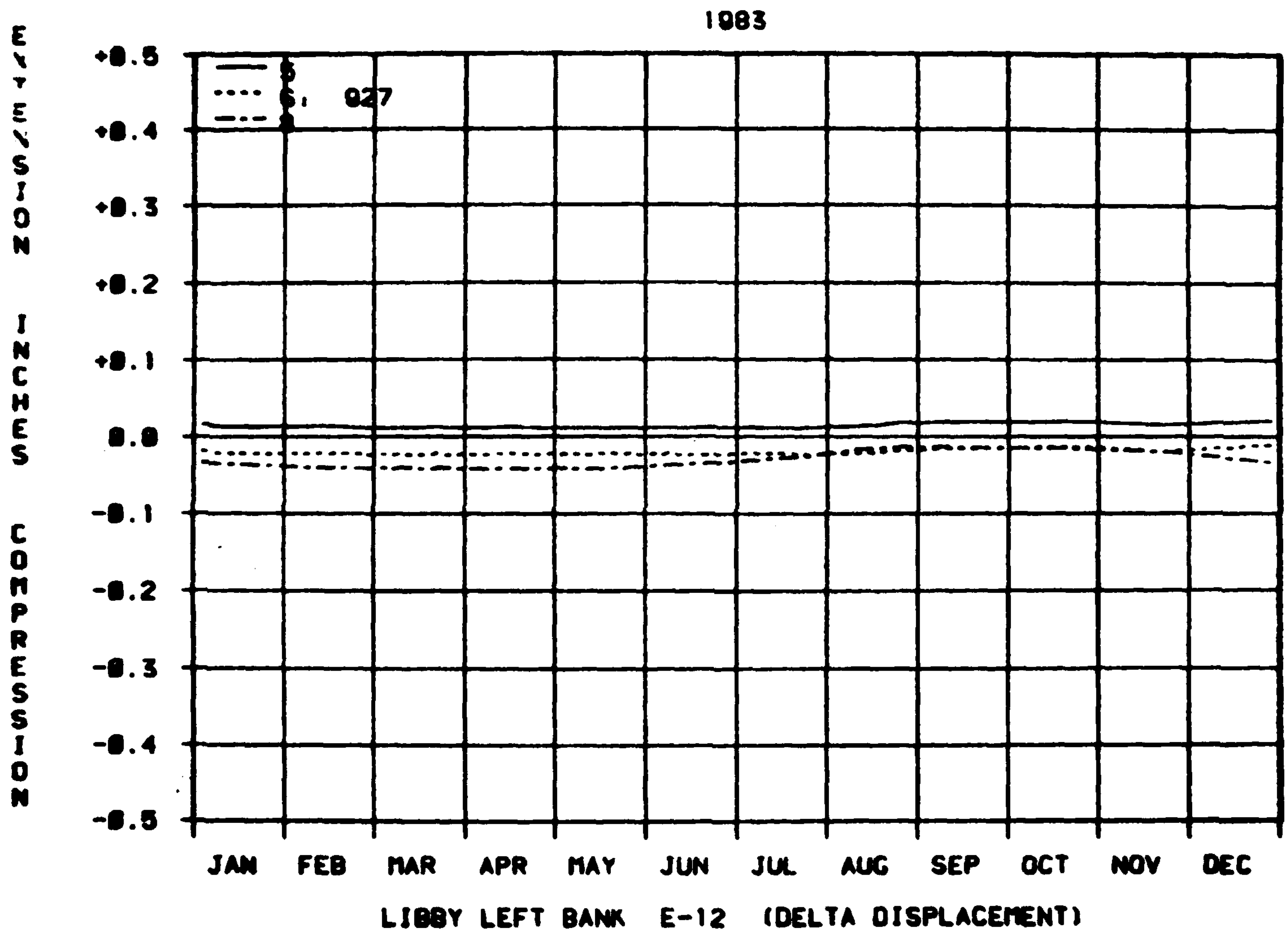


0: TOTAL
1: HIDDEN FAULT
2
3: 928
4
EXTENSION
INCHES
OMPRESSION
+0.5
+0.4
+0.3
+0.2
+0.1
0.0
-0.1
-0.2
-0.3
-0.4
-0.5
1978
1979
1980
1981
1982
LIBBY LEFT BANK E-12 (DELTA DISPLACEMENT)

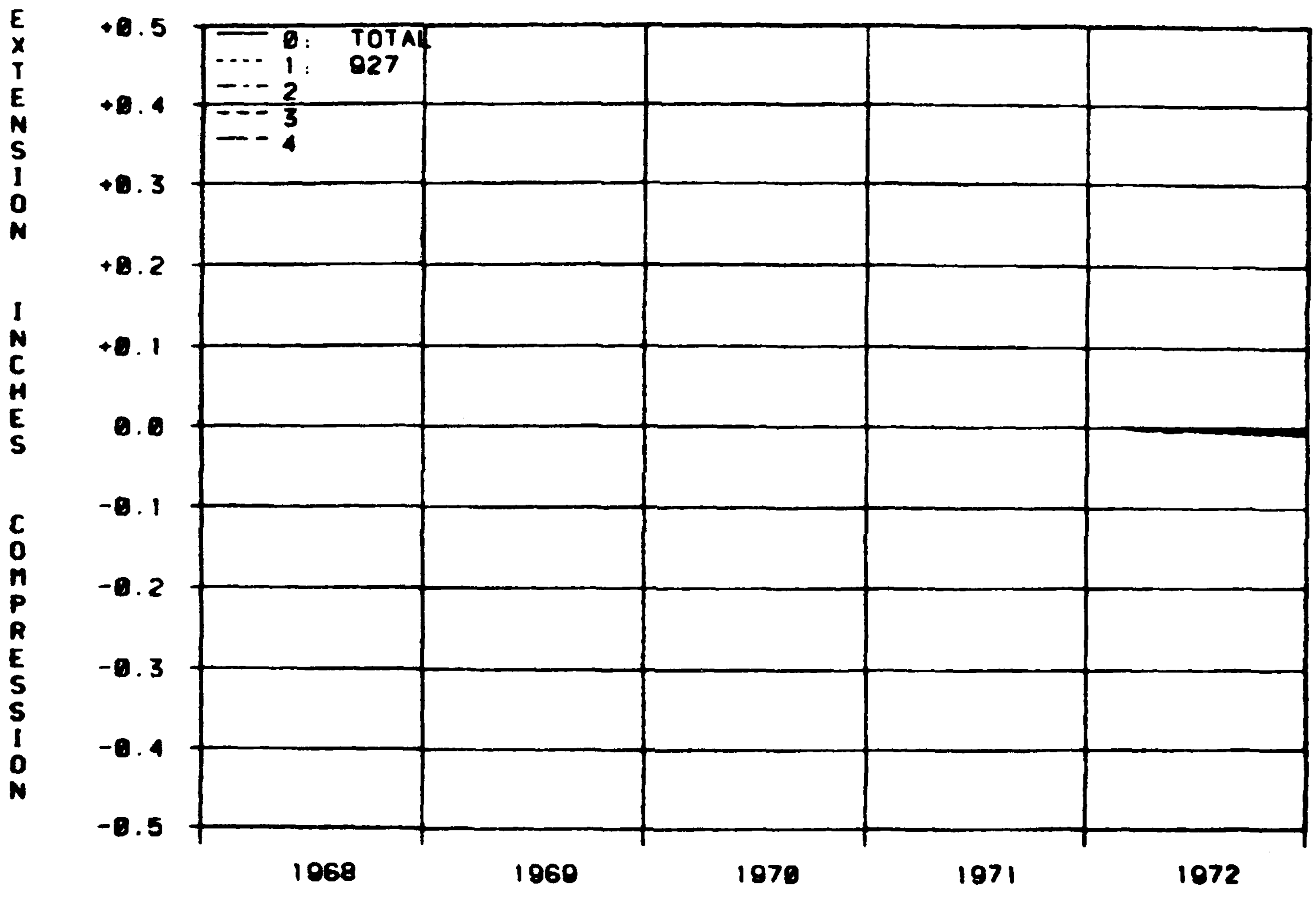


LIBBY LEFT BANK E-12 (DELTA DISPLACEMENT)

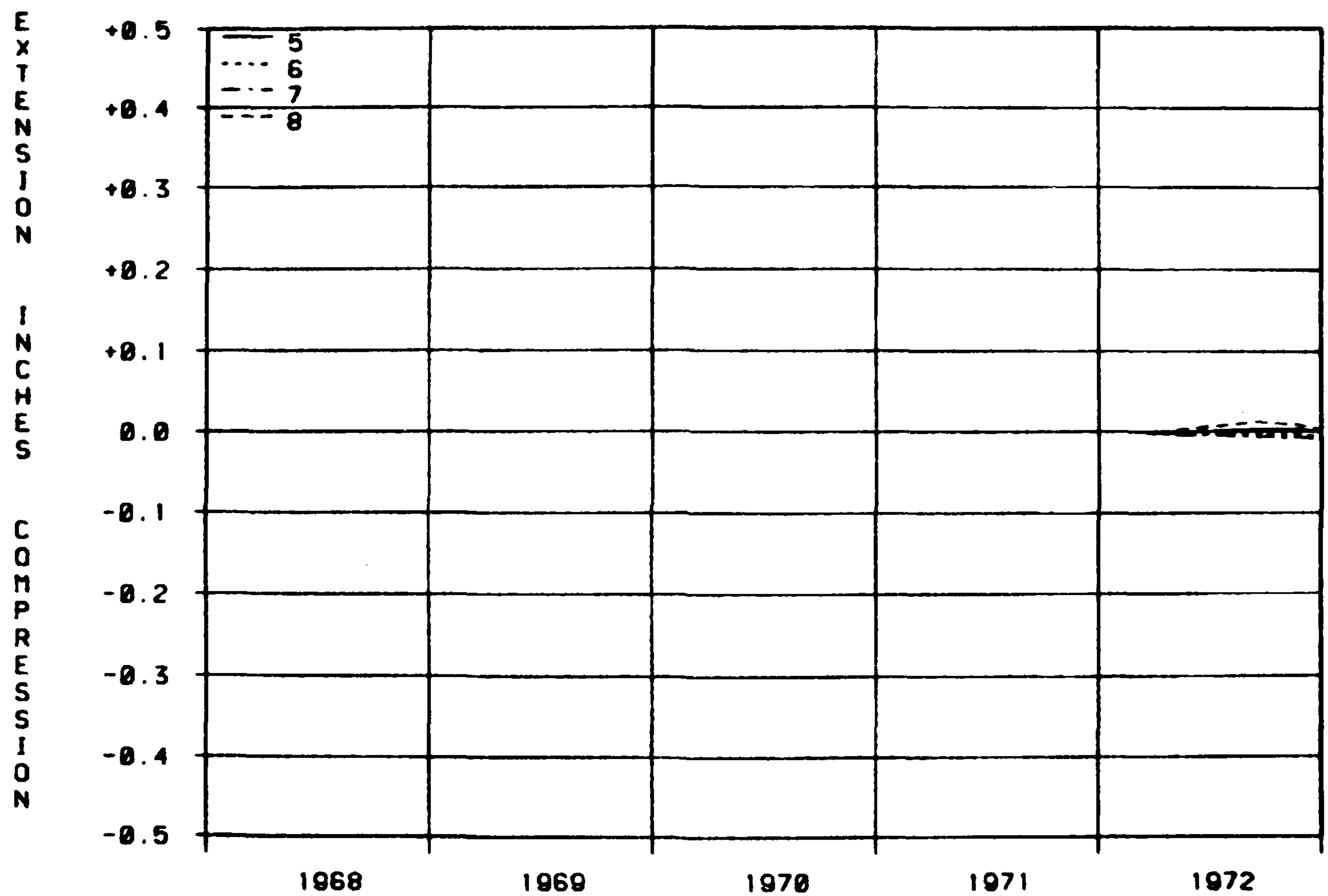

1983
0: TOTAL
1: HIDDEN FAULT
2
3: 928
4
EXTENSION INCHES COMPRESSION
+0.5
+0.4
+0.3
+0.2
+0.1
0.0
-0.1
-0.2
-0.3
-0.4
-0.5
JAN FEB MAR APR MAY JUN JUL AUG SEP OCT NOV DEC
LIBBY LEFT BANK E-12 (DELTA DISPLACEMENT)



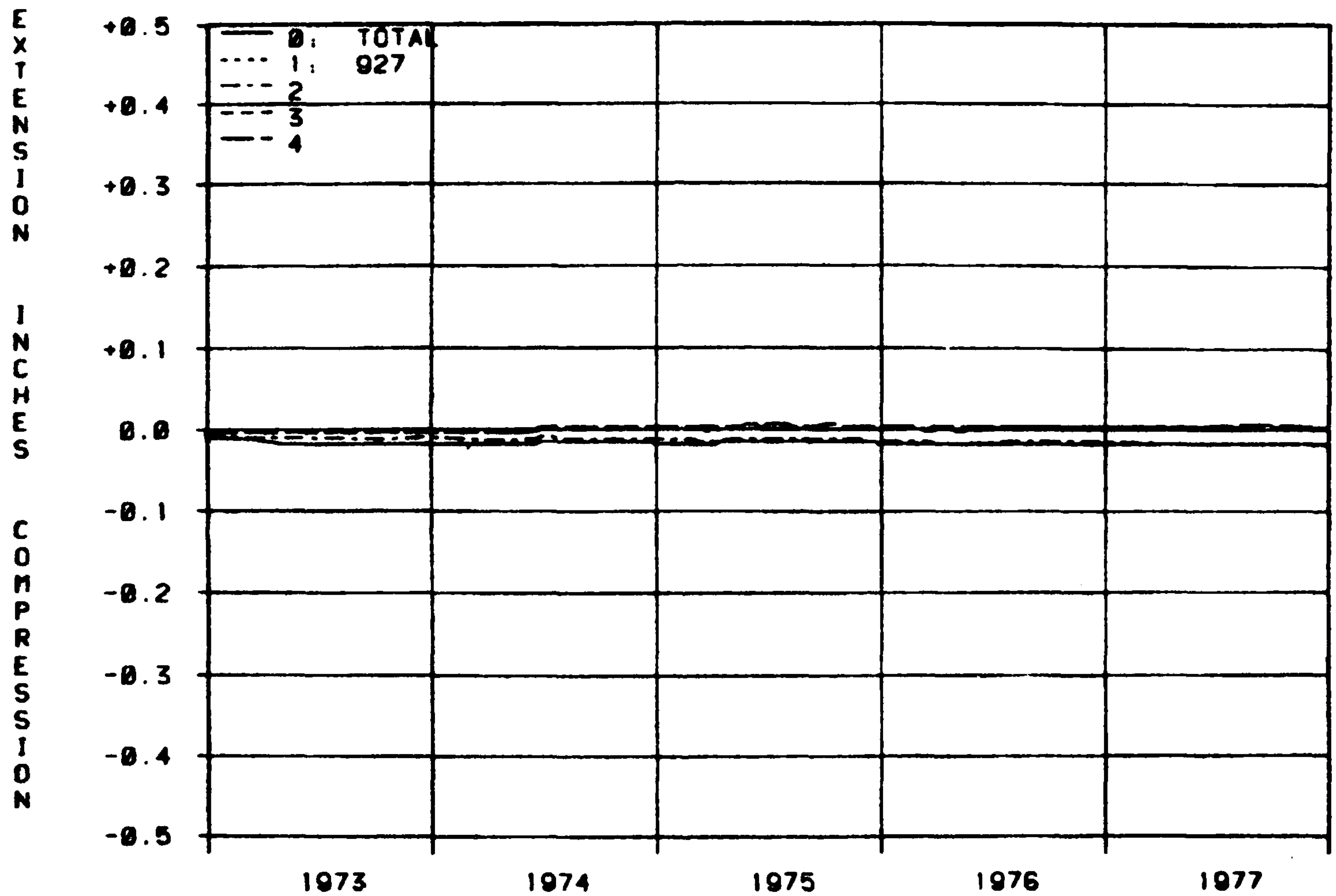
1983
EXTENSION INCHES COMPRESSION
+0.5
+0.4
+0.3
+0.2
+0.1
0.0
-0.1
-0.2
-0.3
-0.4
-0.5
927
JAN FEB MAR APR MAY JUN JUL AUG SEP OCT NOV DEC
LIBBY LEFT BANK E-12 (DELTA DISPLACEMENT)



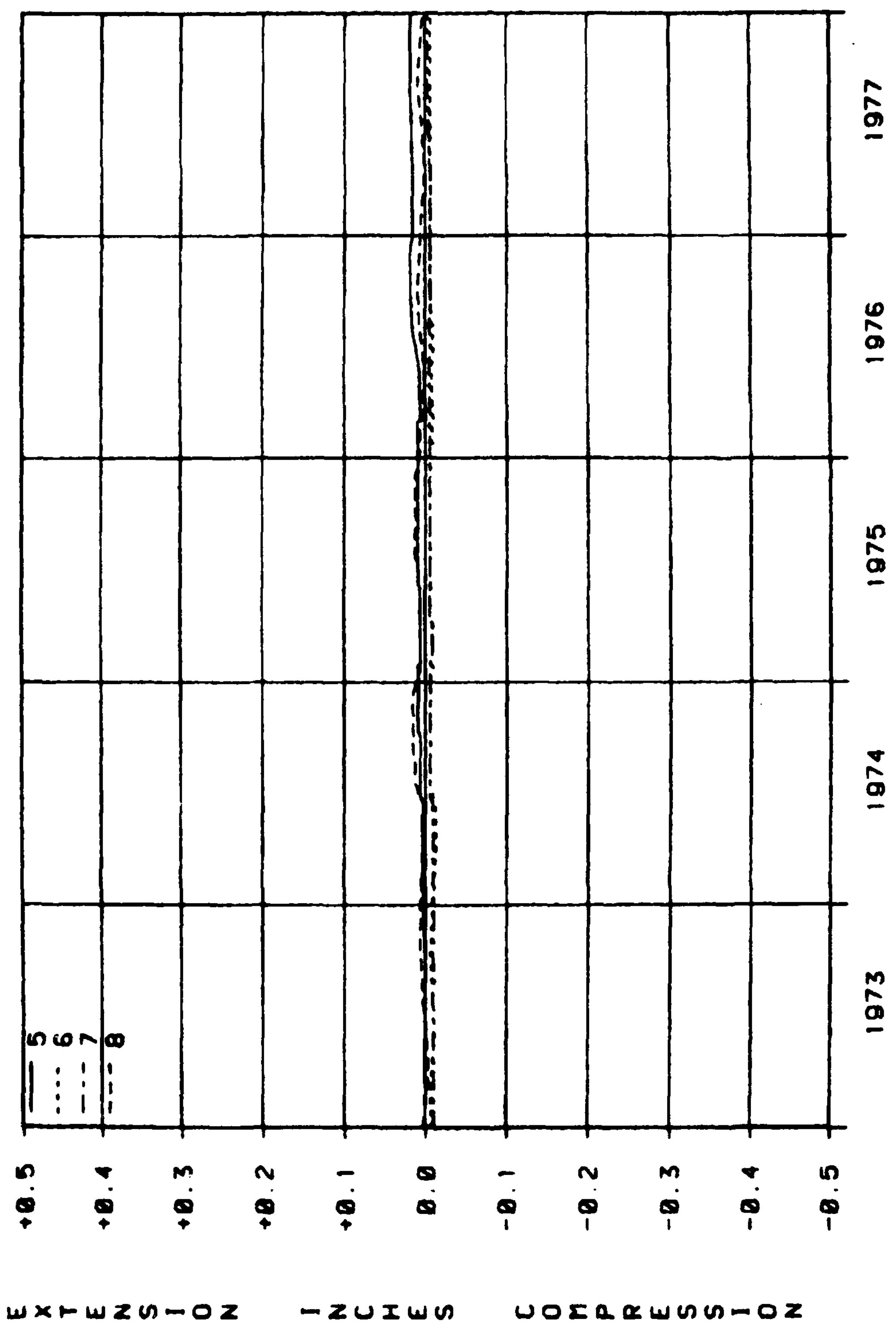
LIBBY LEFT BANK E-13 (DELTA DISPLACEMENT)



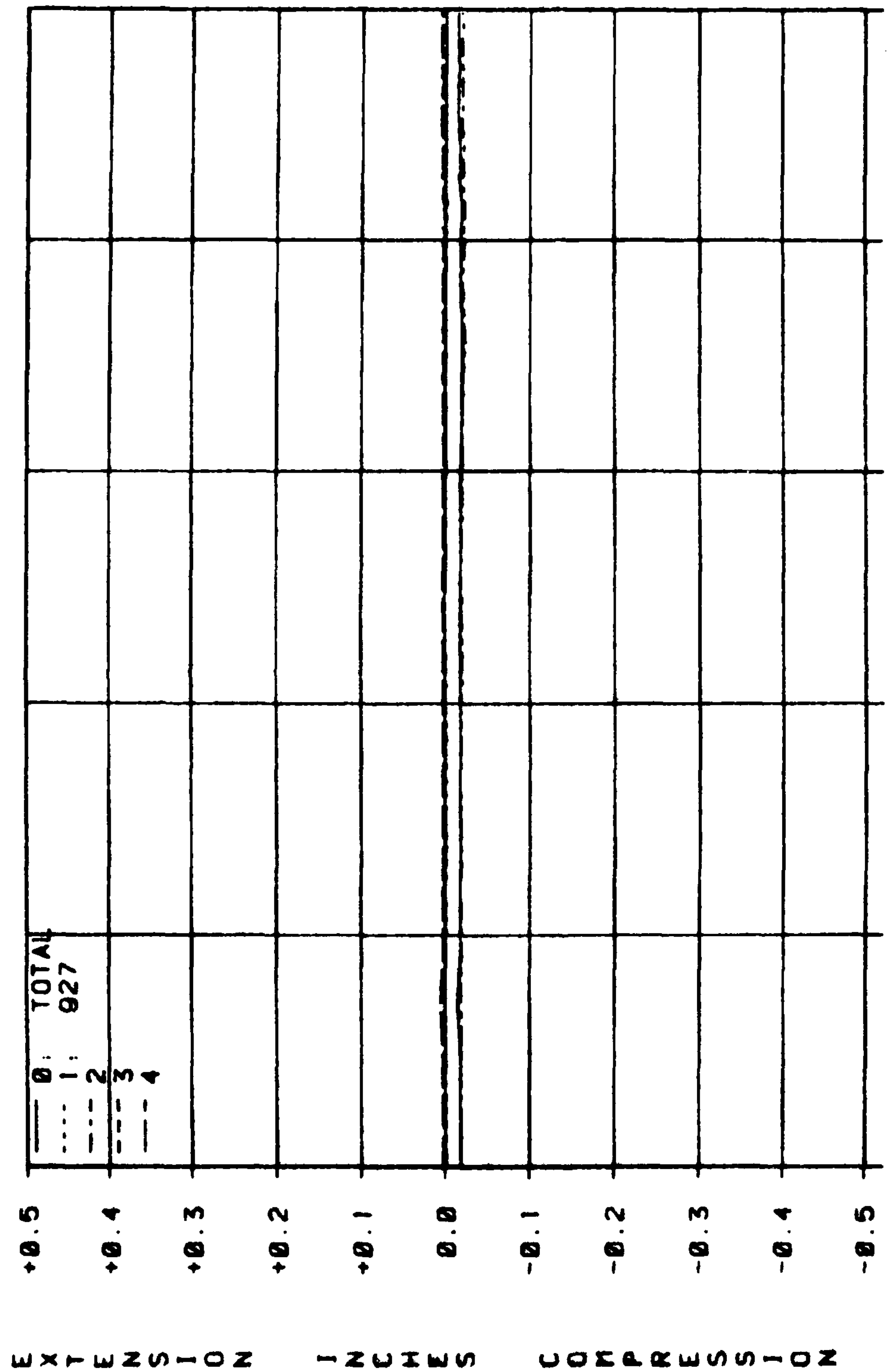
LIBBY LEFT BANK E-13 (DELTA DISPLACEMENT)



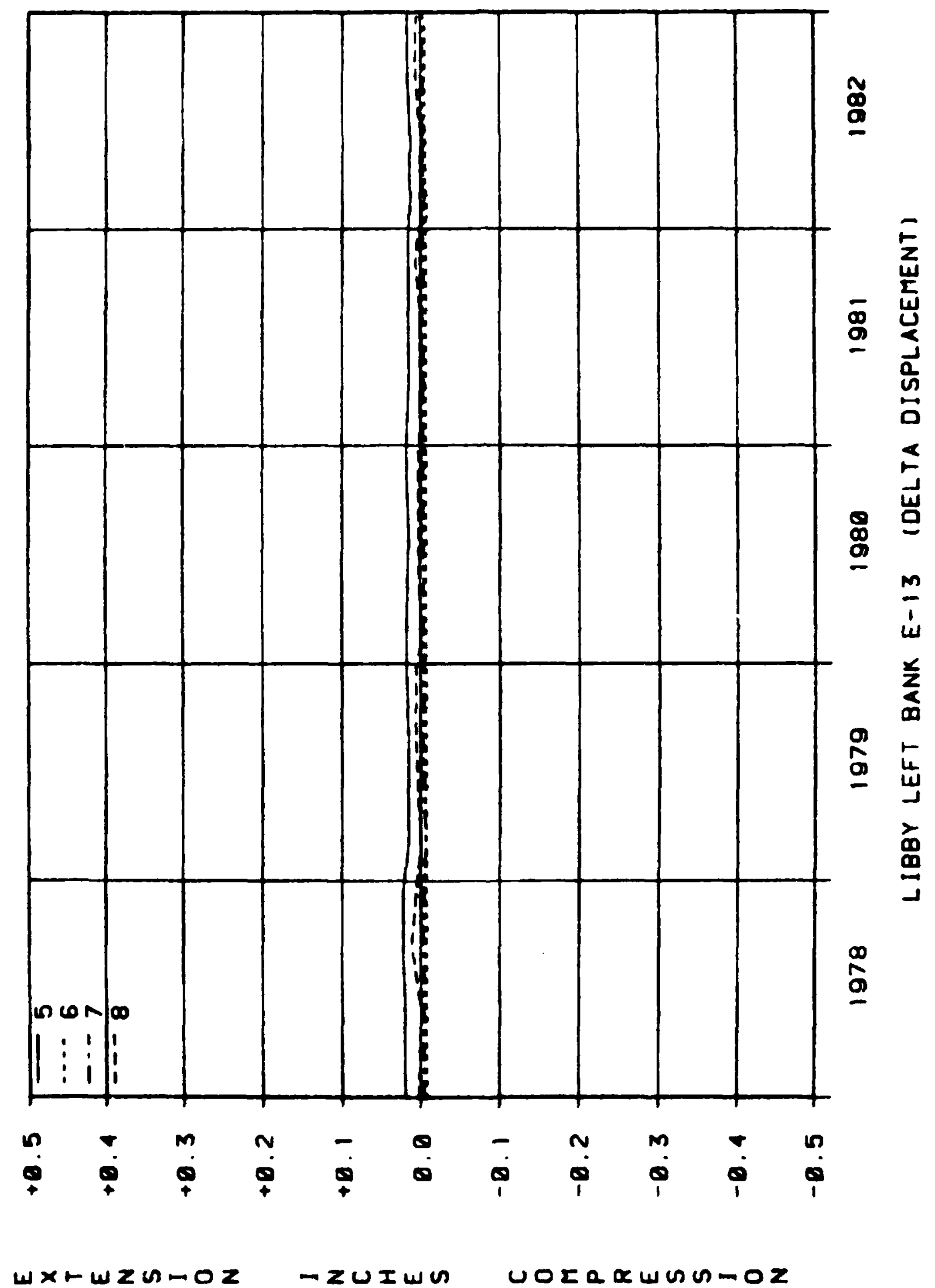
LIBBY LEFT BANK E-13 (DELTA DISPLACEMENT)

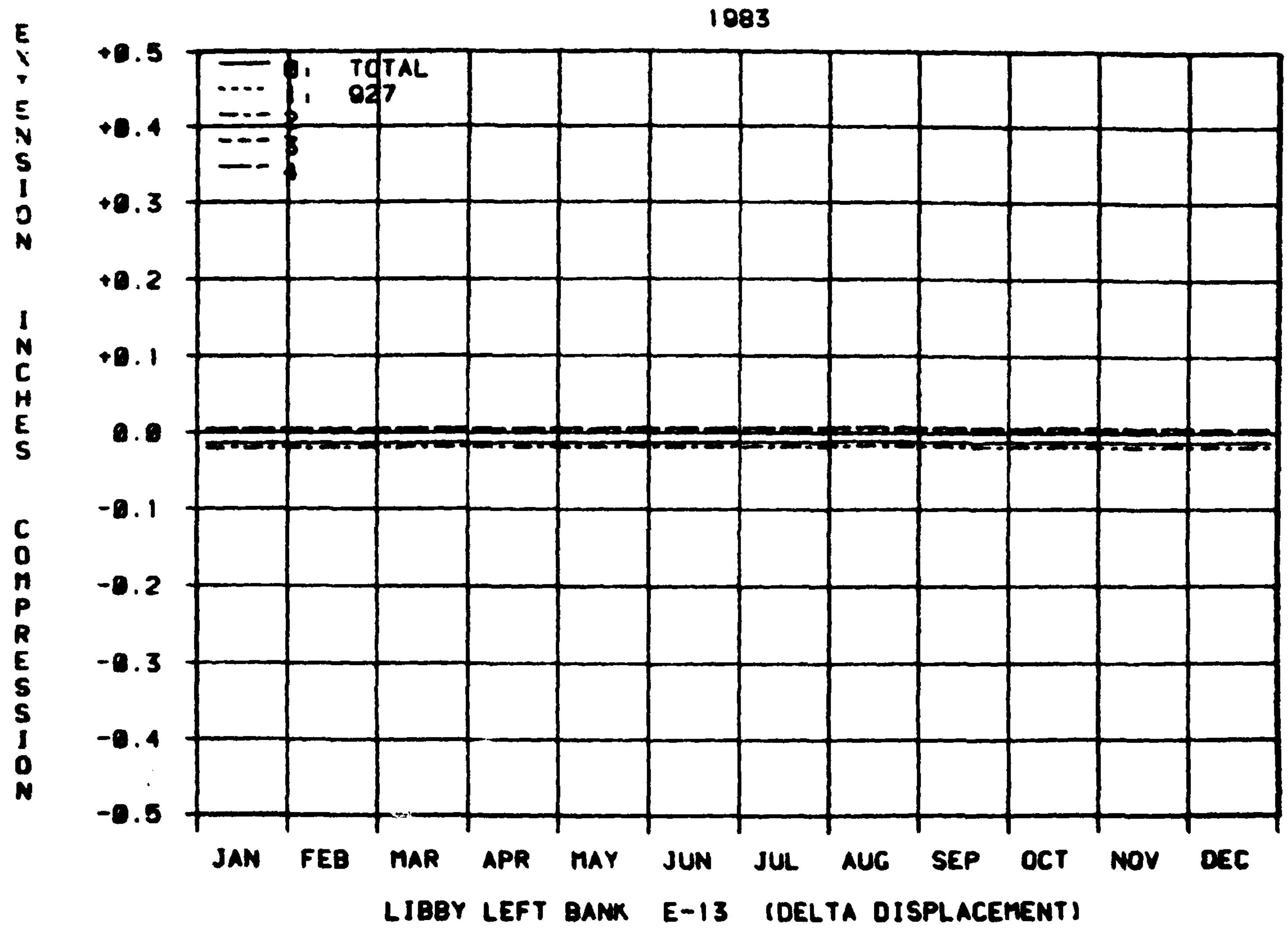


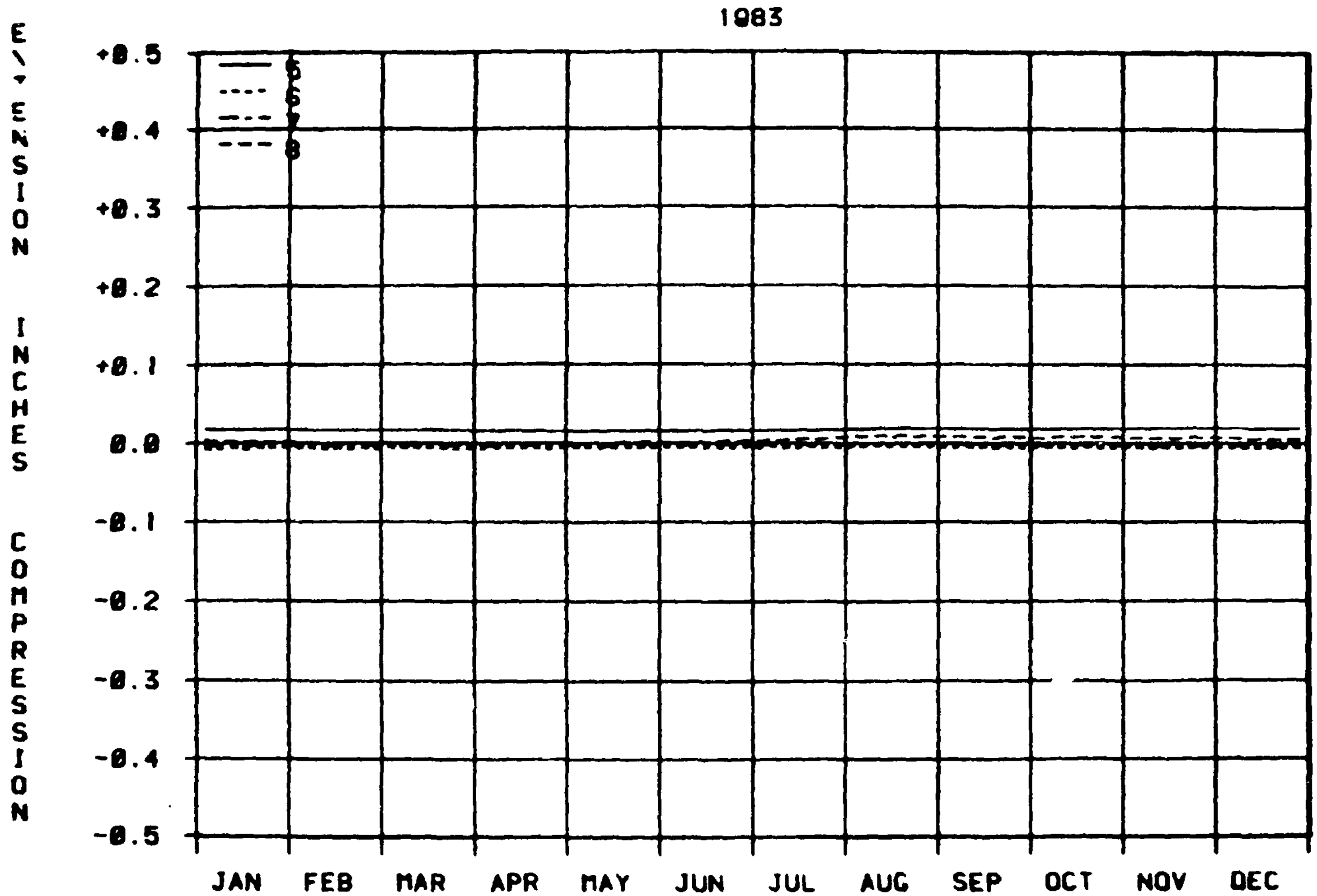
LIBBY LEFT BANK E-13 (DELTA DISPLACEMENT)



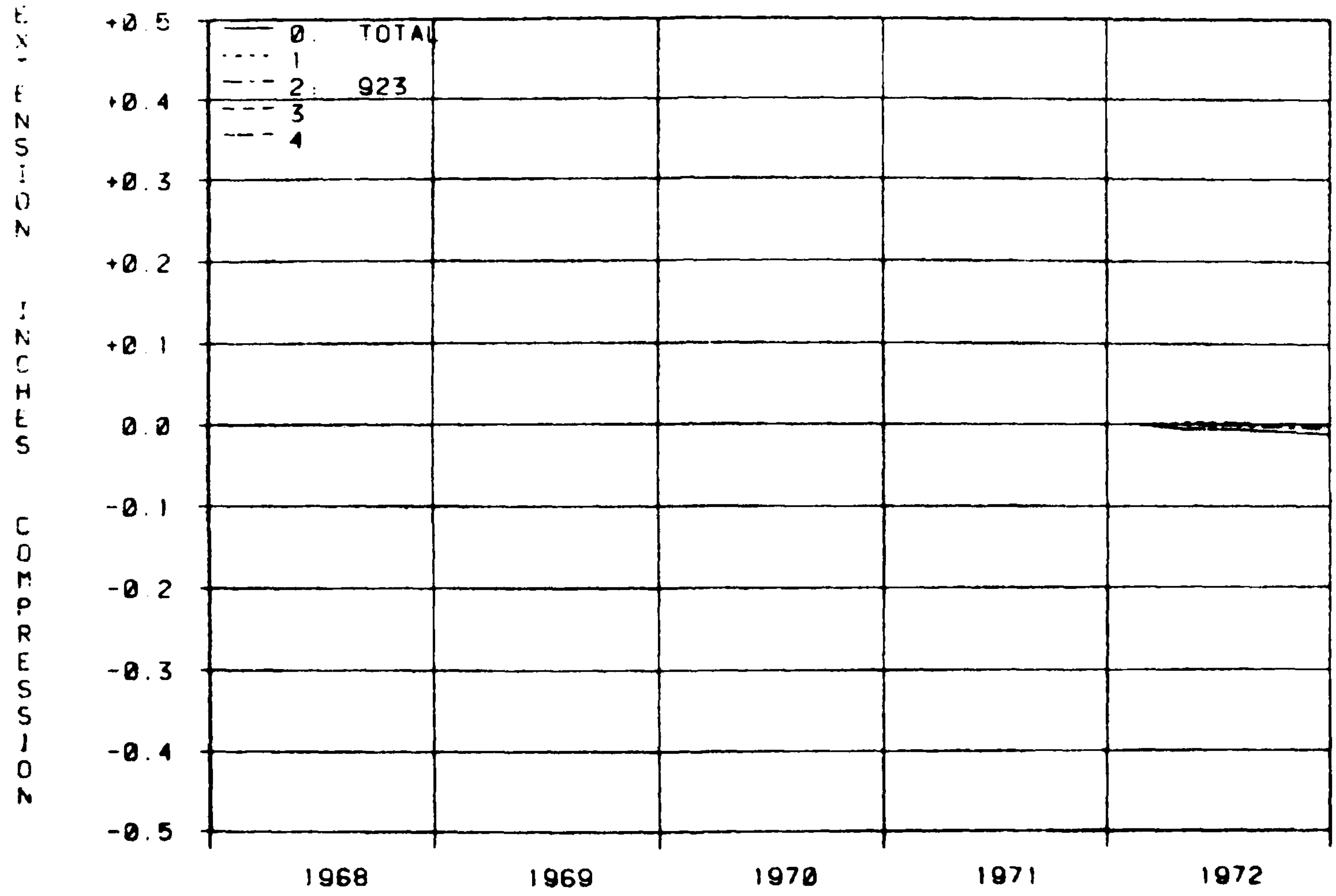
LIBBY LEFT BANK E-13 (DELTA DISPLACEMENT)


LIBBY LEFT BANK E-13 (DELTA DISPLACEMENT)
1978
1979
1980
1981
1982
5
6
7
8
+0.5
+0.4
+0.3
+0.2
+0.1
0.0
-0.1
-0.2
-0.3
-0.4
-0.5
EXTENSION INCHES COMPRESSION

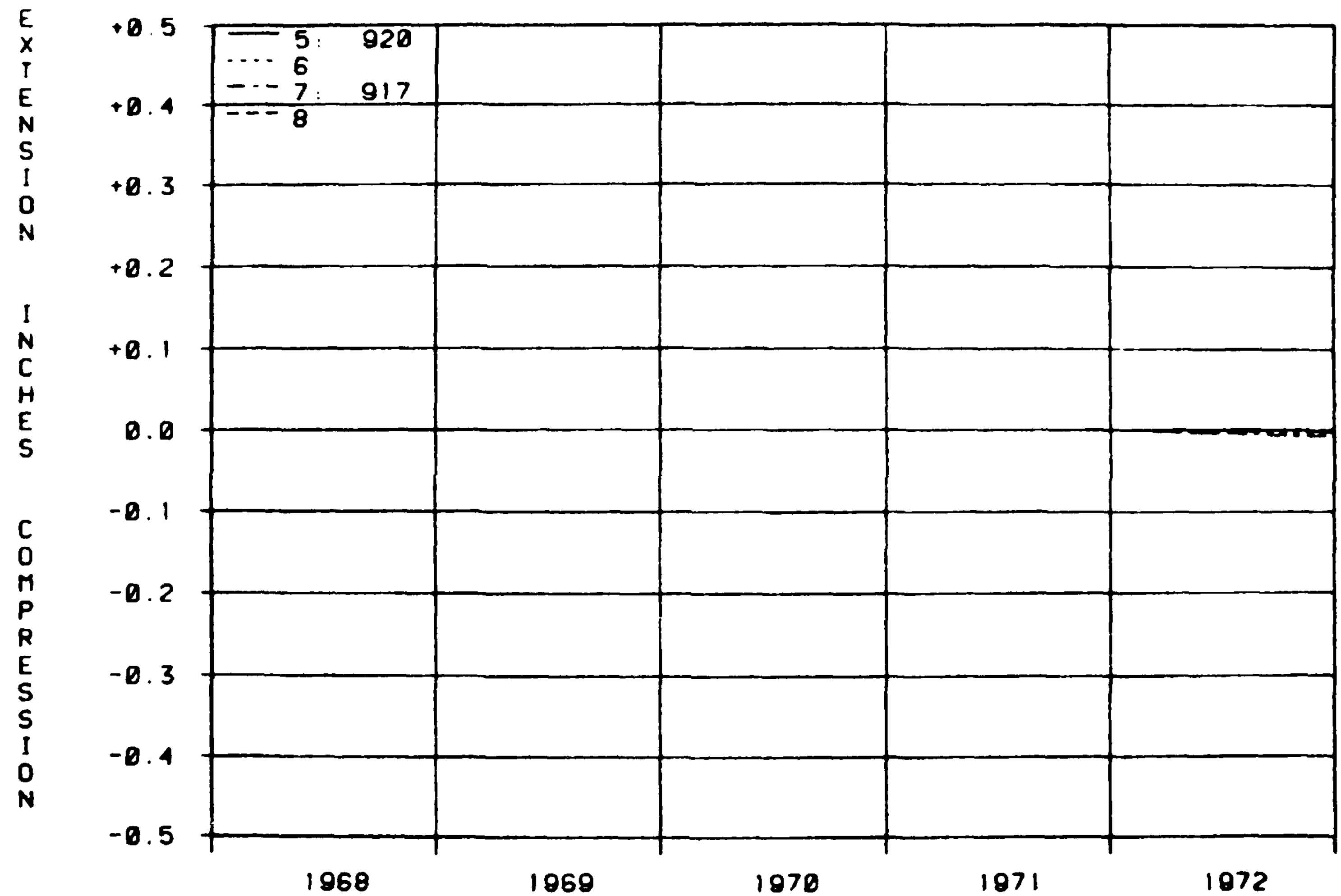

1983
EXTENSION INCHES COMPRESSION
+0.5
+0.4
+0.3
+0.2
+0.1
0.0
-0.1
-0.2
-0.3
-0.4
-0.5
0: TOTAL
1: 927
2
3
4
JAN FEB MAR APR MAY JUN JUL AUG SEP OCT NOV DEC
LIBBY LEFT BANK E-13 (DELTA DISPLACEMENT)



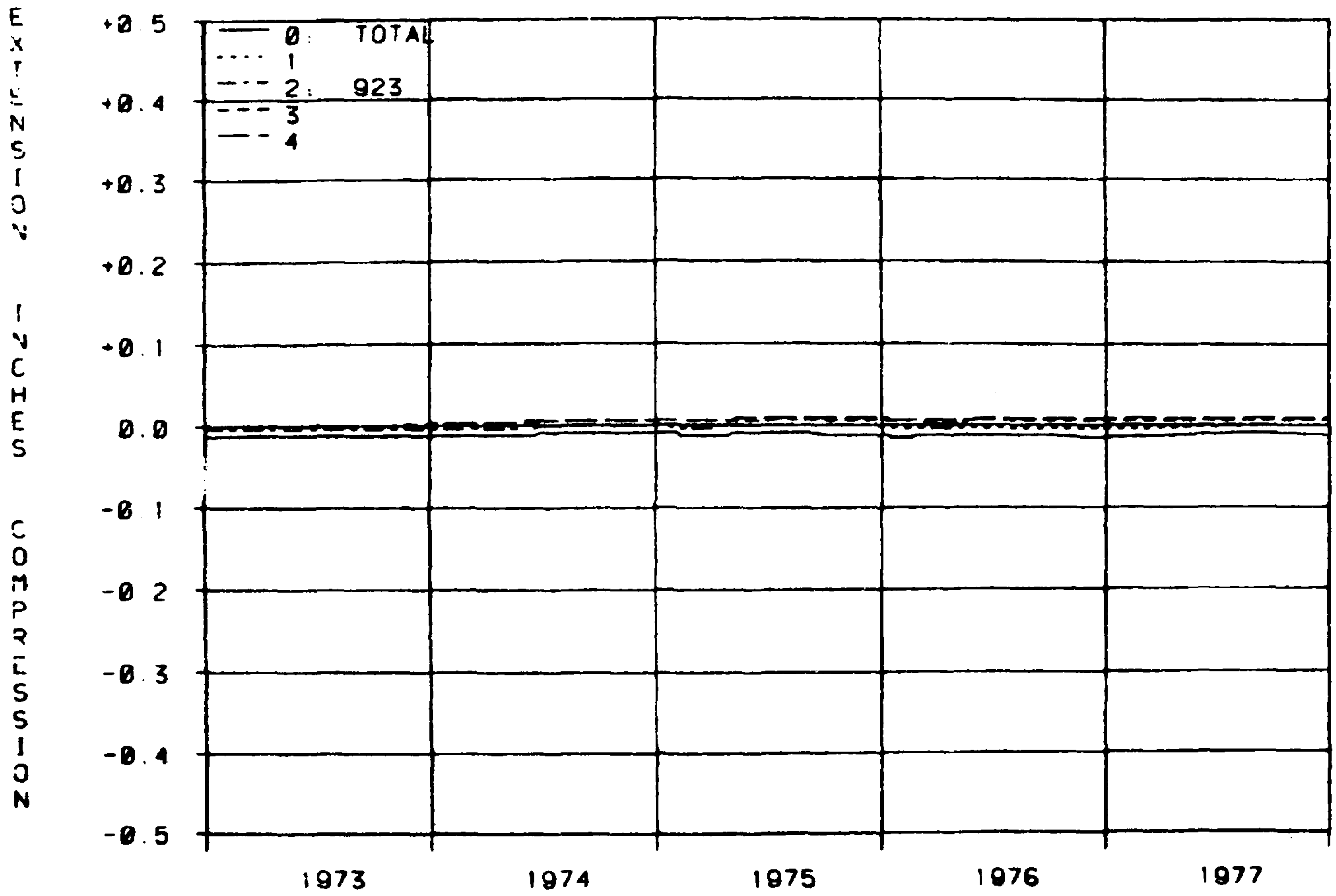
LIBBY LEFT BANK E-13 (DELTA DISPLACEMENT)



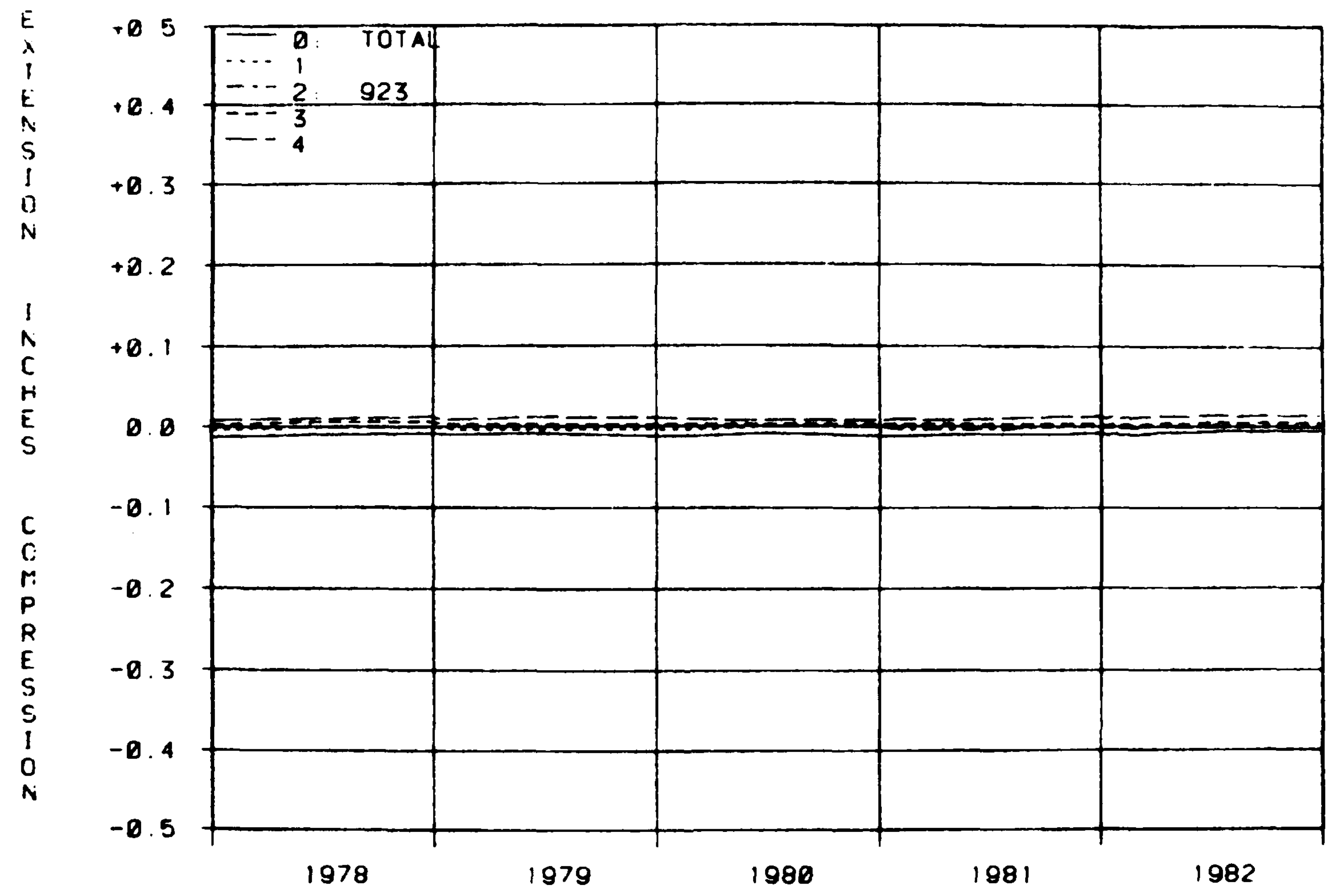
LIBBY LEFT BANK E-14 (DELTA DISPLACEMENT)



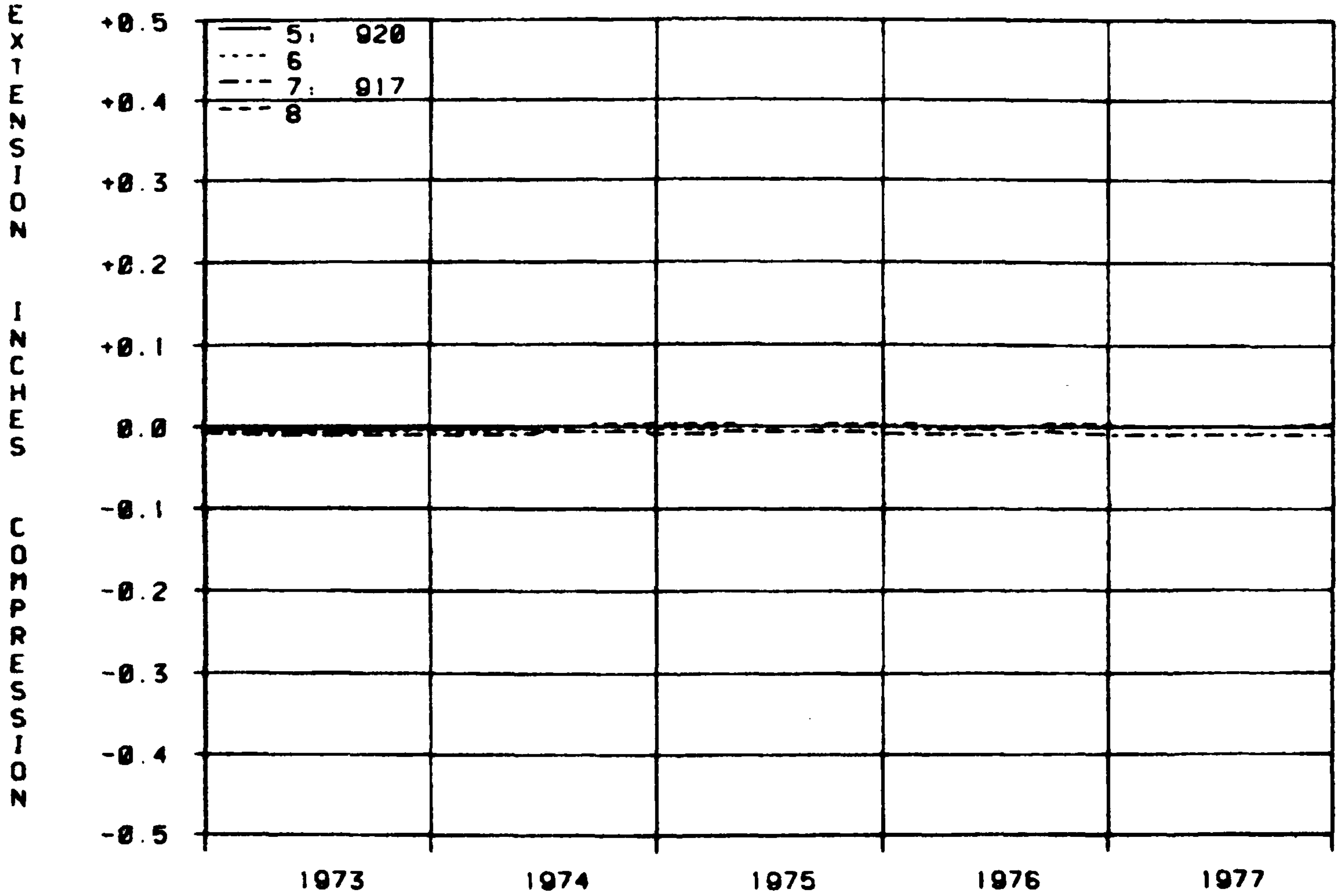
LIBBY LEFT BANK E-14 (DELTA DISPLACEMENT)



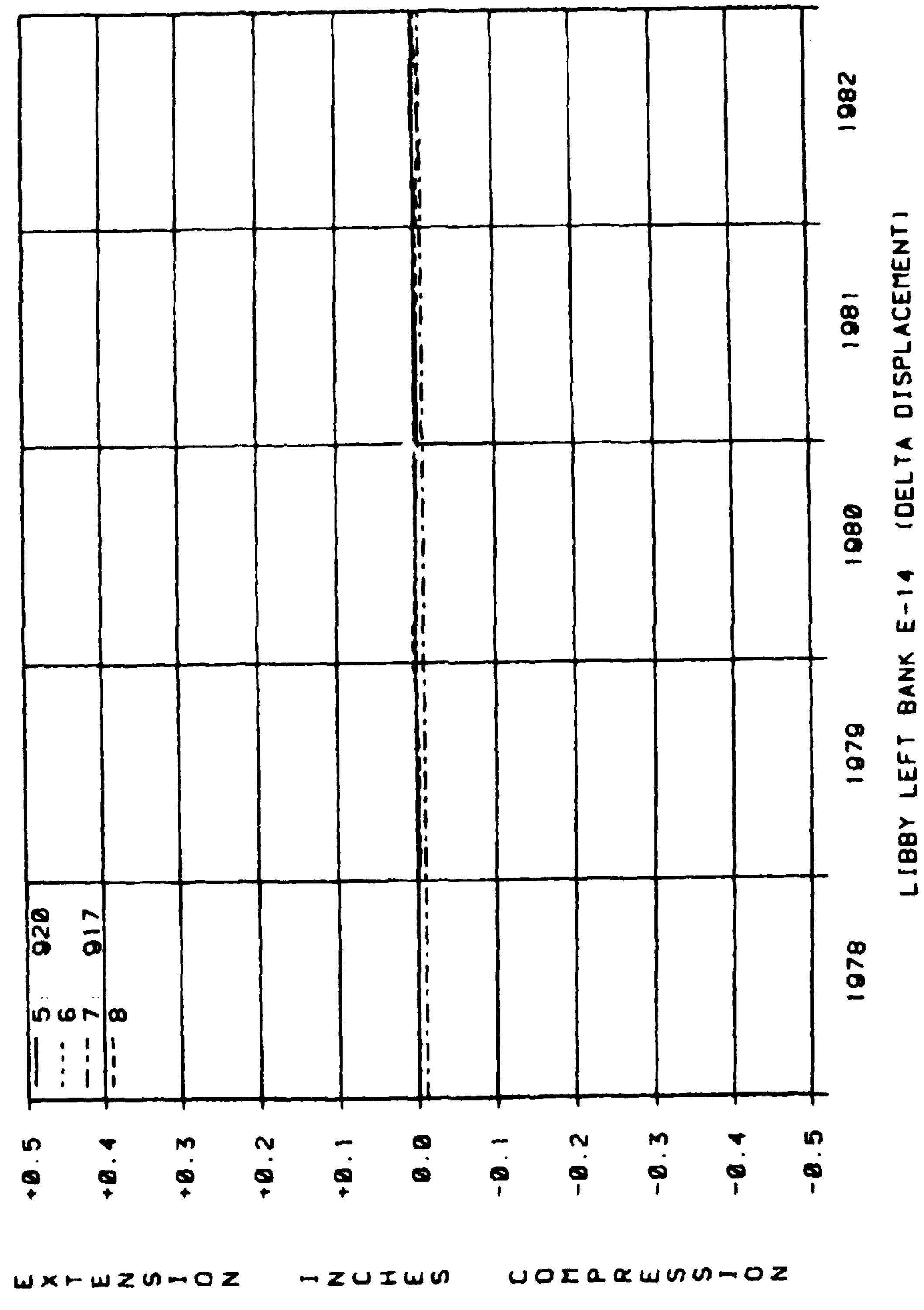
LIBBY LEFT BANK E-14 (DELTA DISPLACEMENT)

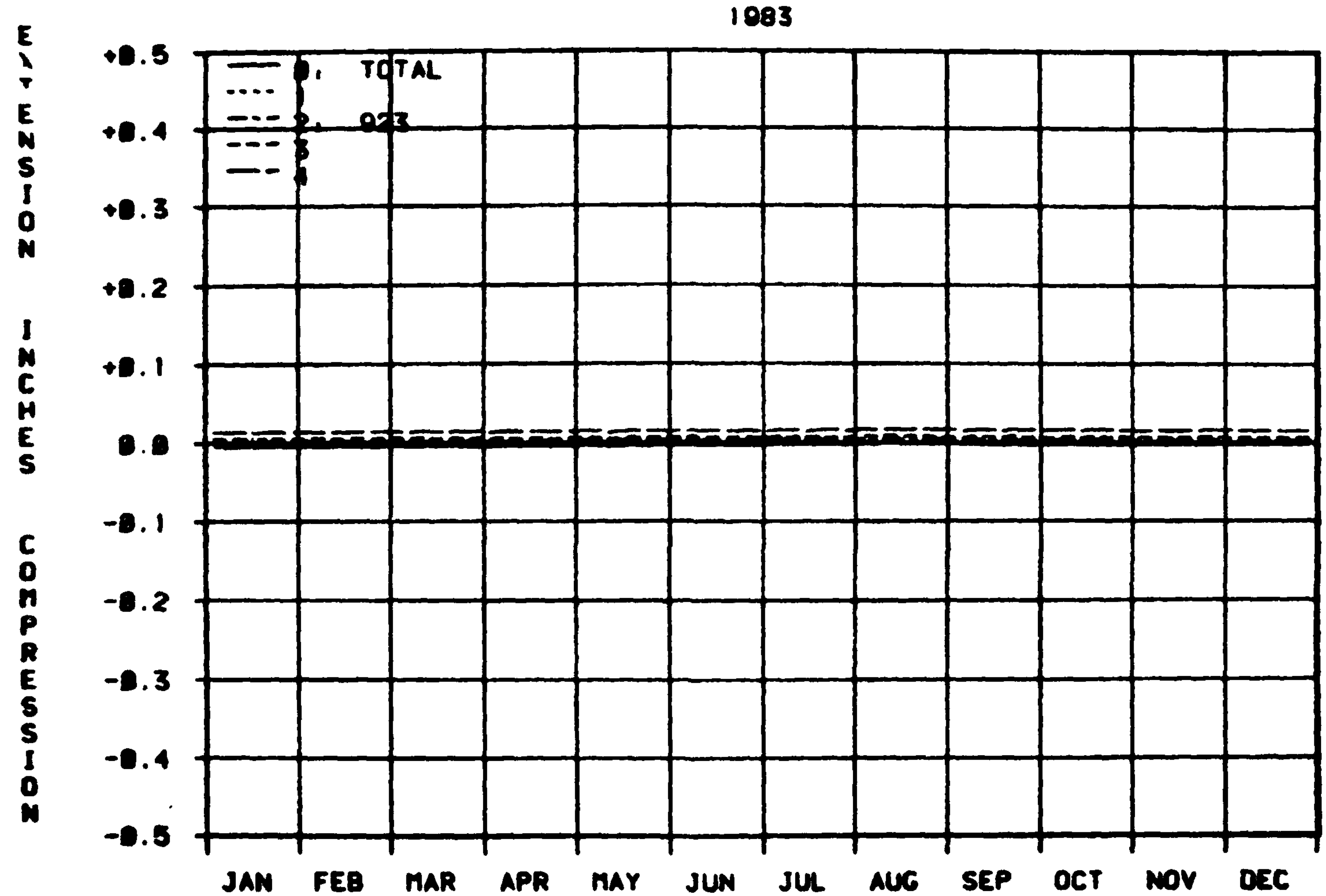


LIBBY LEFT BANK E-14 (DELTA DISPLACEMENT)

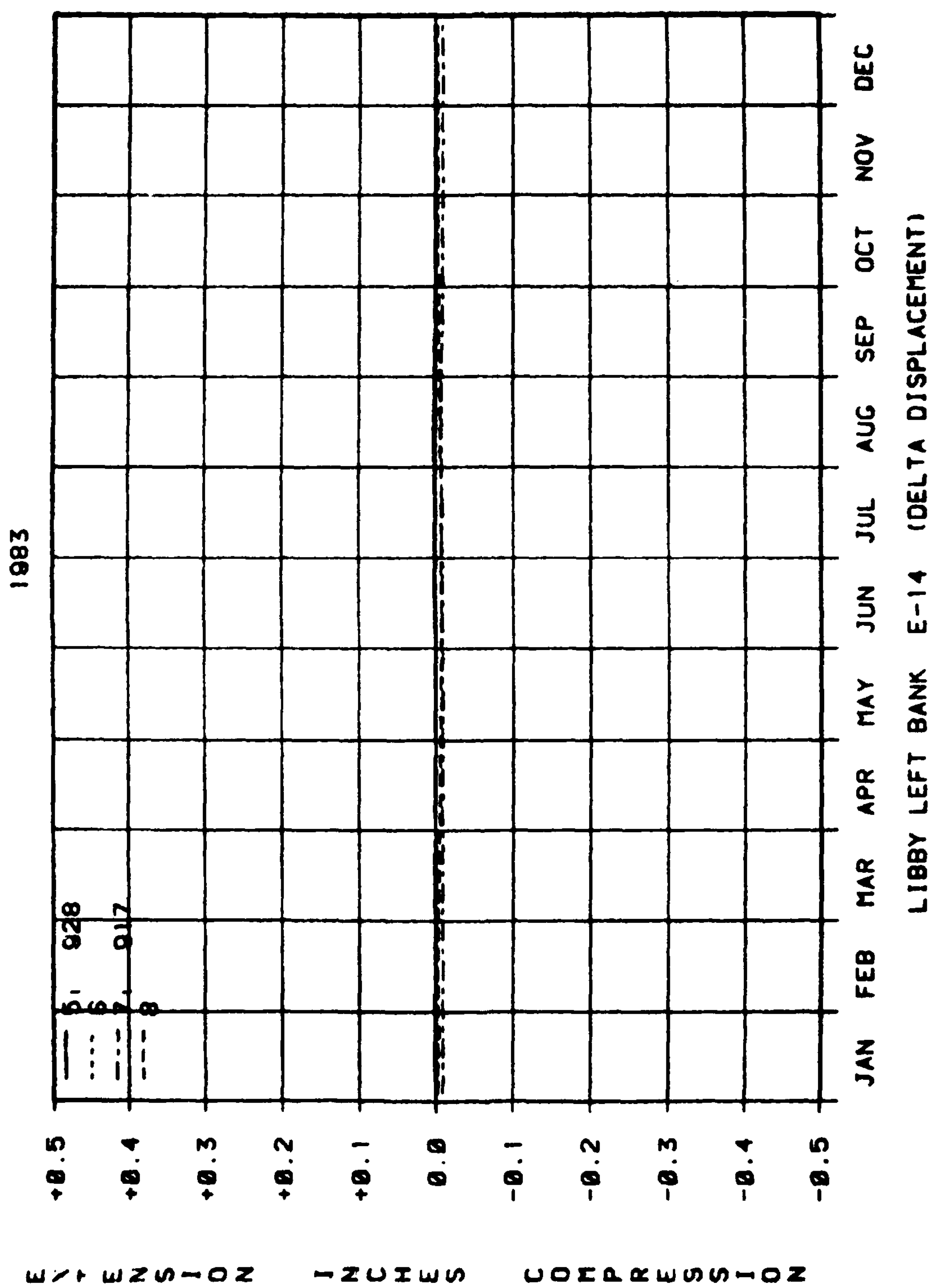


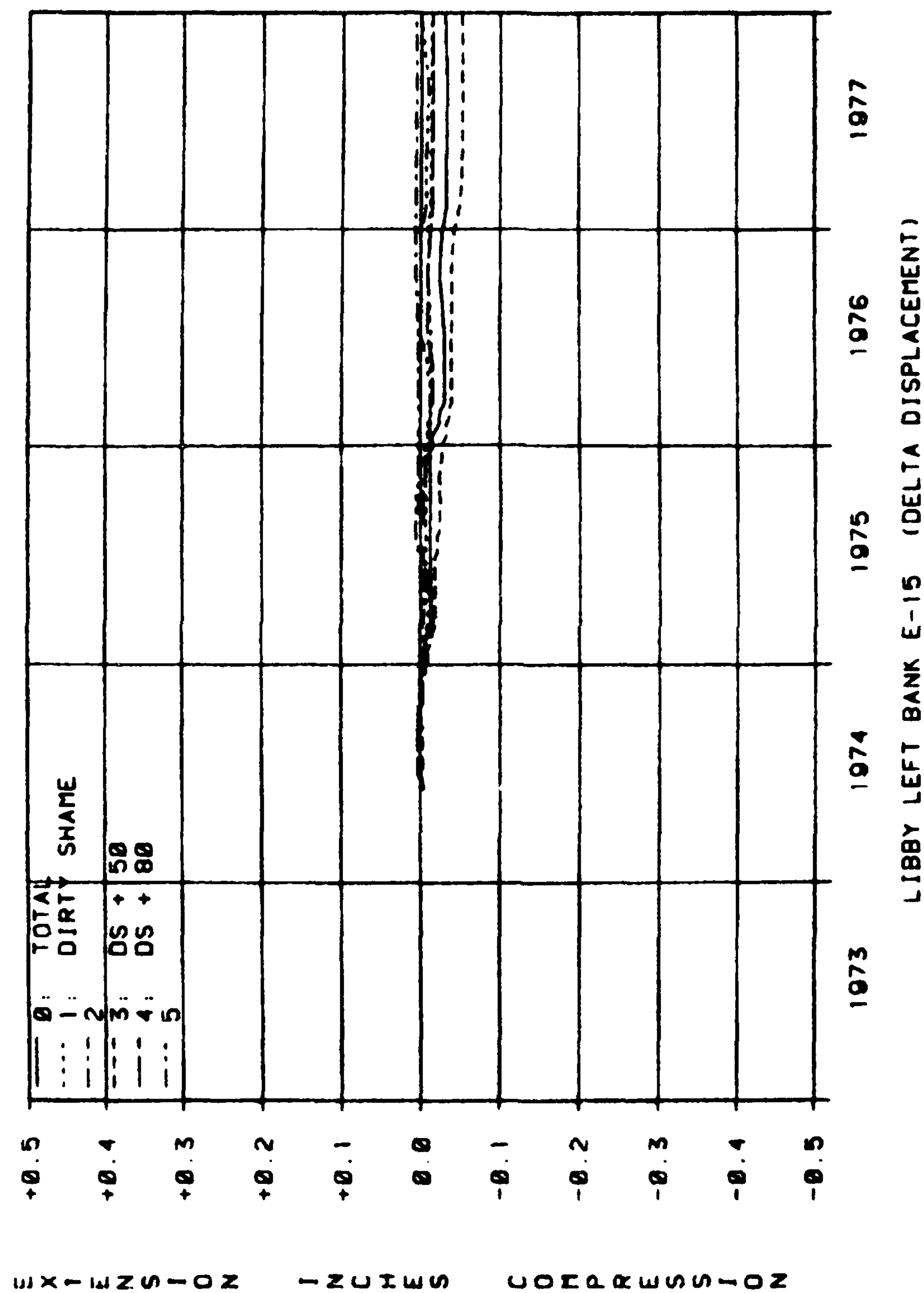
LIBBY LEFT BANK E-14 (DELTA DISPLACEMENT)

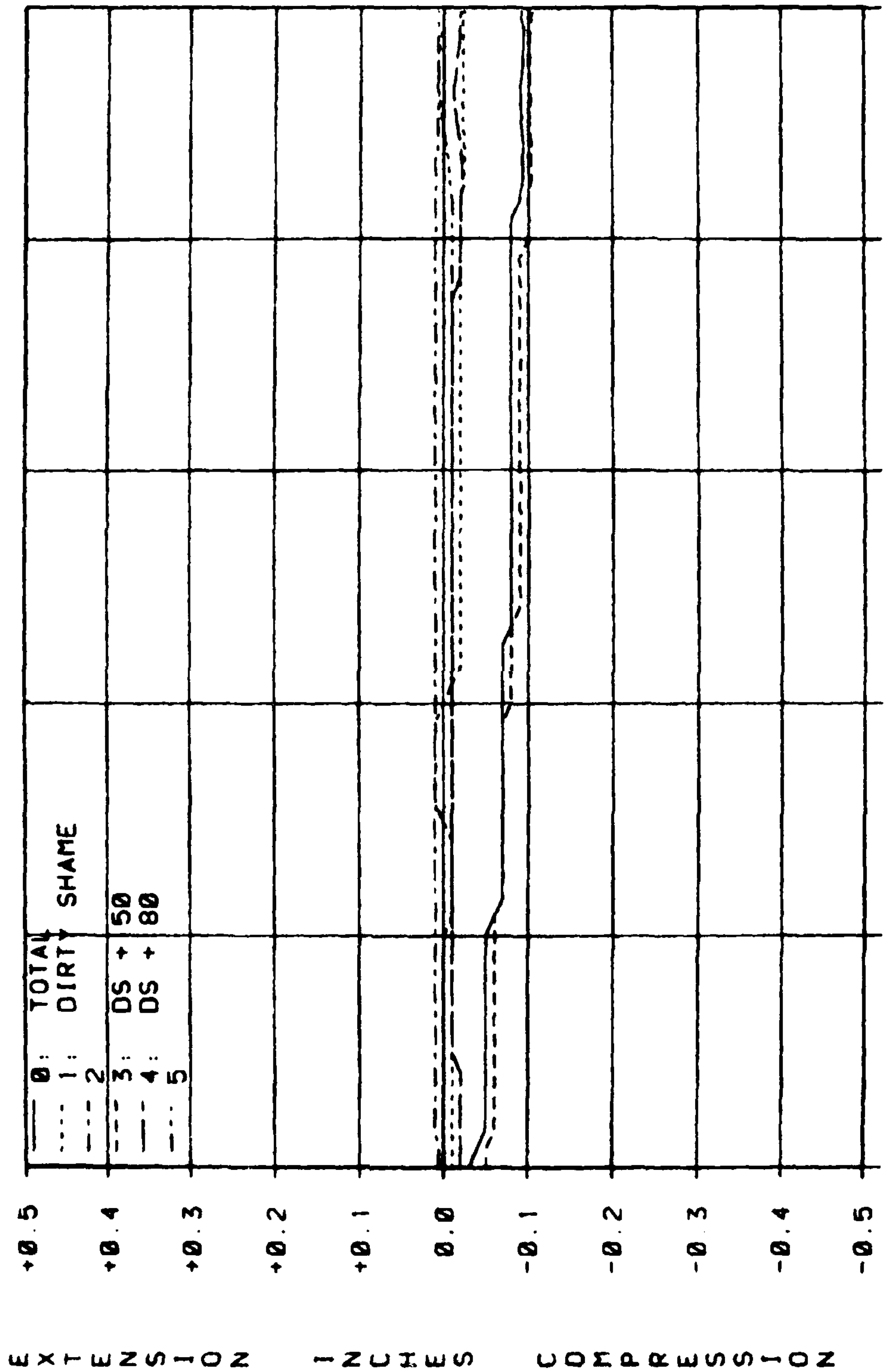

LIBBY LEFT BANK E-14 (DELTA DISPLACEMENT)
5 920
6
7 917
8
+0.5
+0.4
+0.3
+0.2
+0.1
0.0
-0.1
-0.2
-0.3
-0.4
-0.5
EXTENSION INCHES COMPRESSION
1978
1979
1980
1981
1982



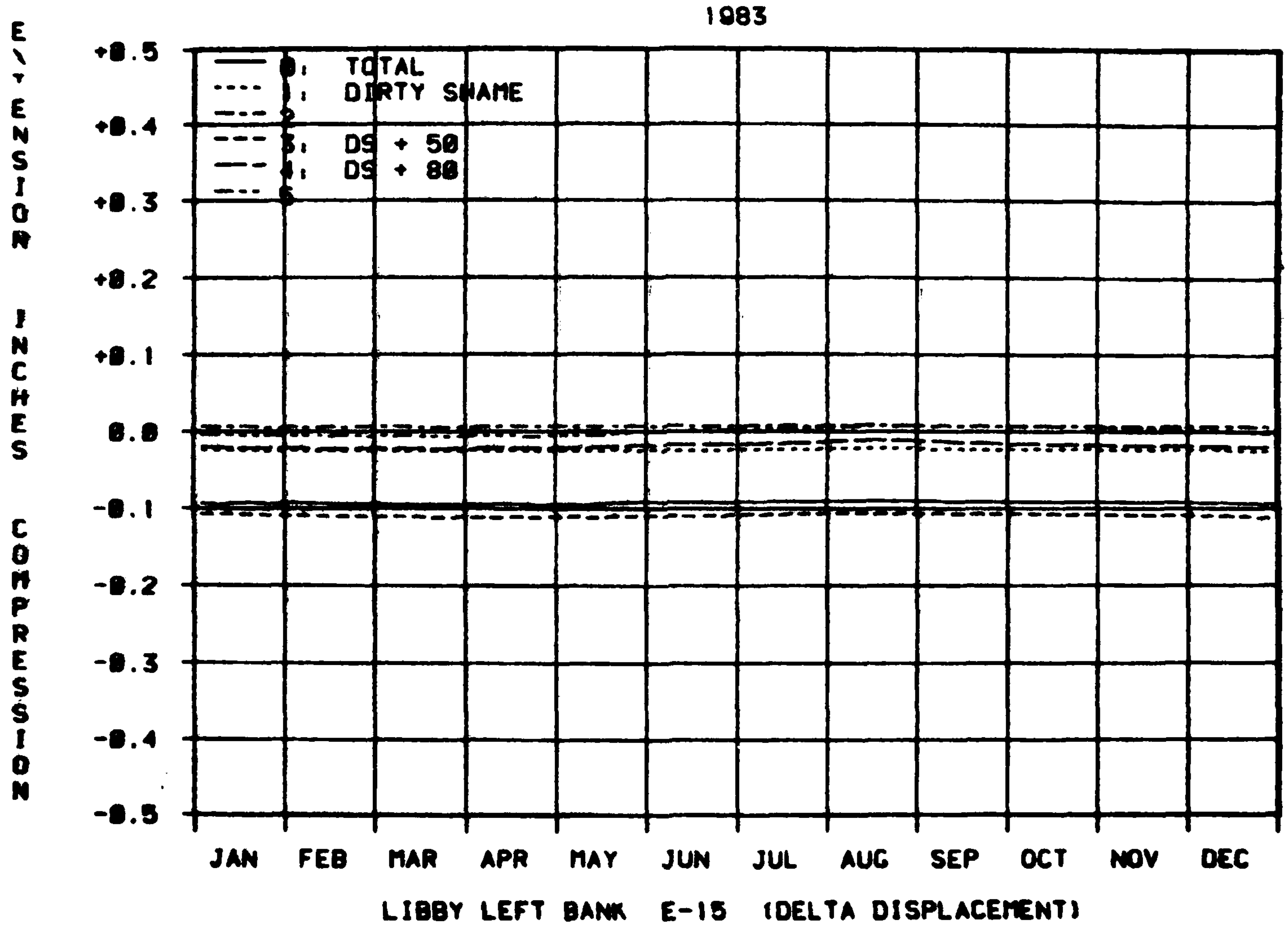
LIBBY LEFT BANK E-14 (DELTA DISPLACEMENT)

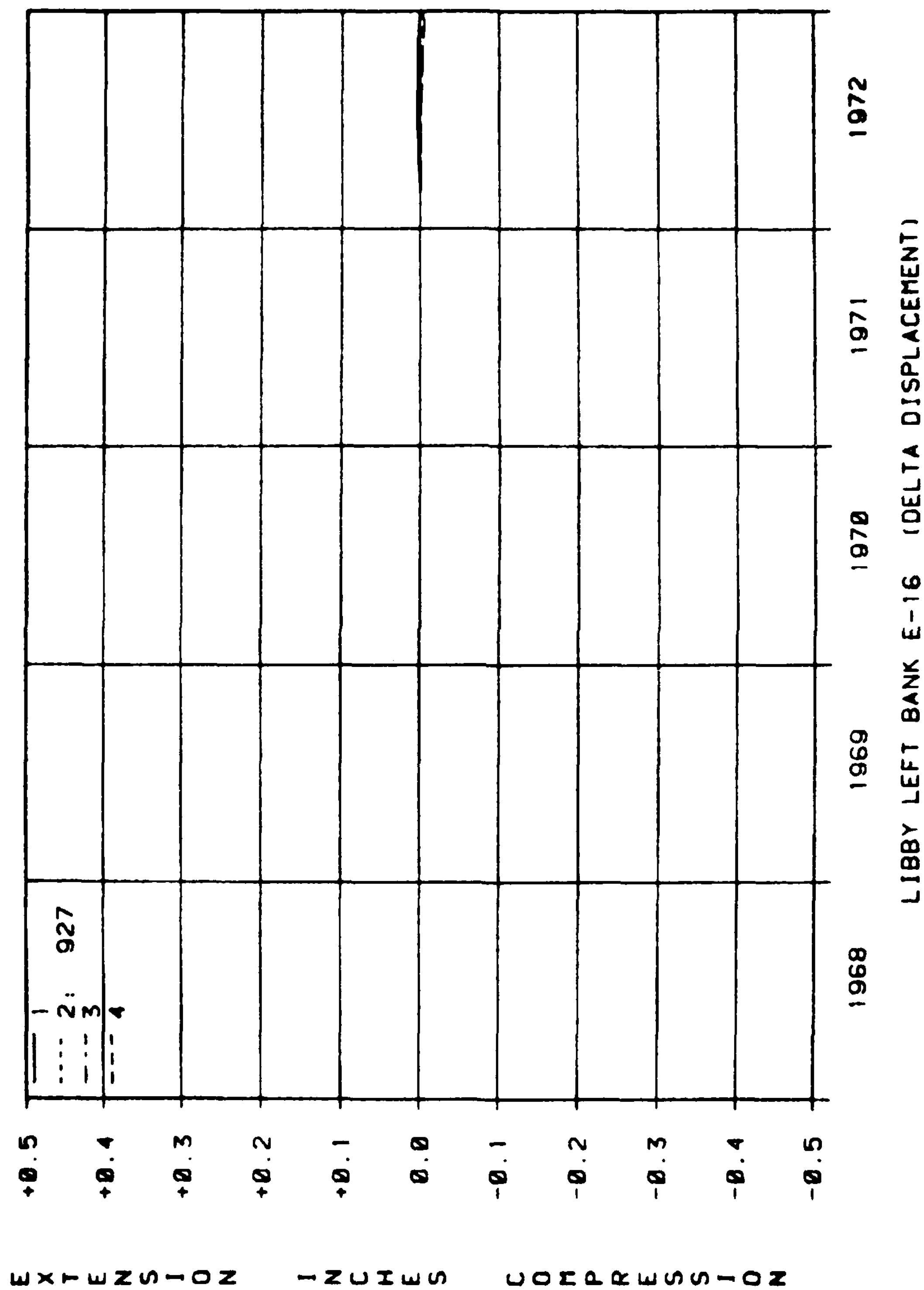

1983
JAN FEB MAR APR MAY JUN JUL AUG SEP OCT NOV DEC
+0.5 +0.4 +0.3 +0.2 +0.1 0.0 -0.1 -0.2 -0.3 -0.4 -0.5
EXTENSION INCHES COMPRESSION
5 928
6
7 917
8
LIBBY LEFT BANK E-14 (DELTA DISPLACEMENT)

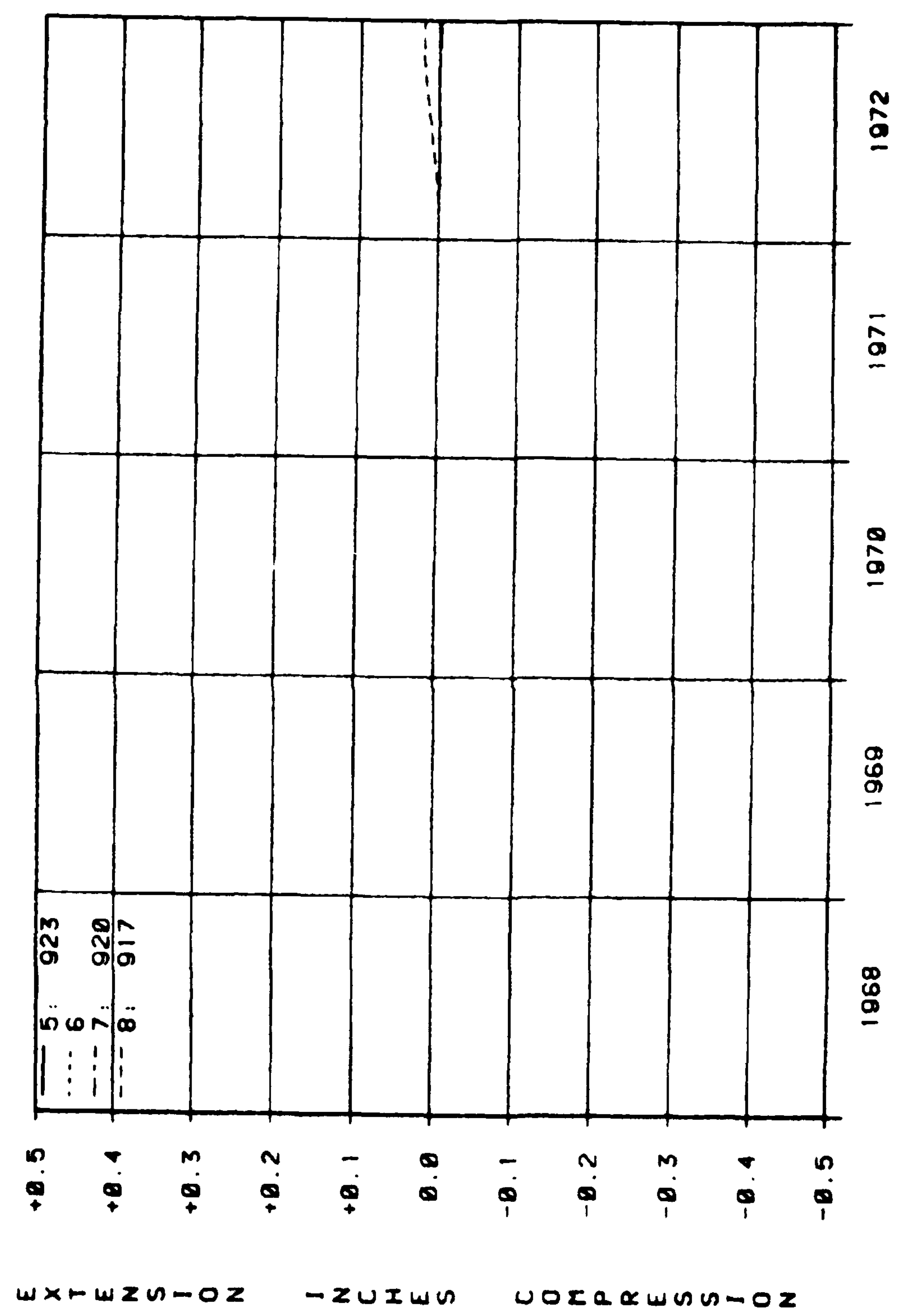

0: TOTAL
1: DIRTY
2: SHAME
3: DS + 50
4: DS + 80
5
+0.5
+0.4
+0.3
+0.2
+0.1
0.0
-0.1
-0.2
-0.3
-0.4
-0.5
EXTENSION INCHES COMPRESSION
1973
1974
1975
1976
1977
LIBBY LEFT BANK E-15 (DELTA DISPLACEMENT)



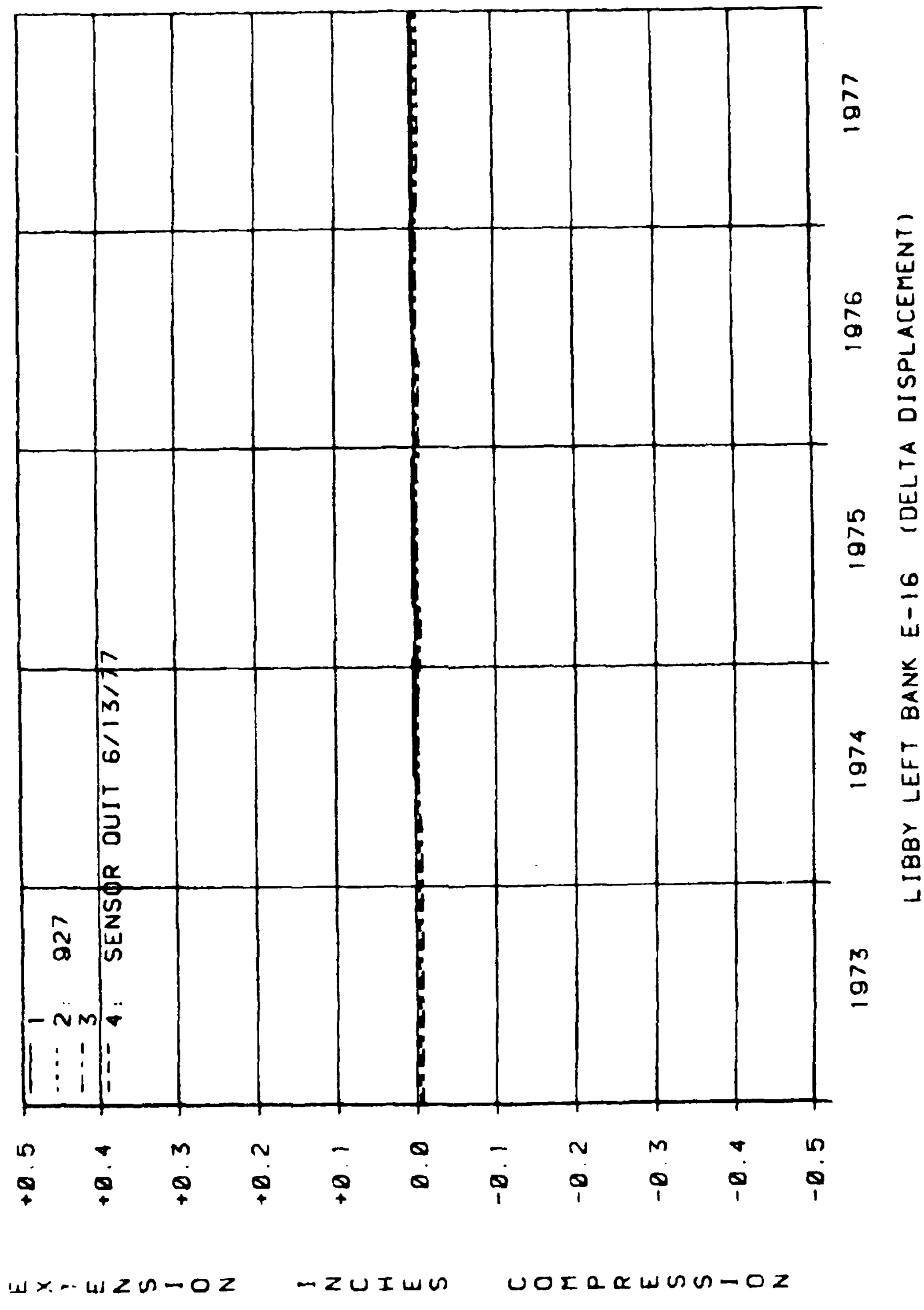
LIBBY LEFT BANK E-15 (DELTA DISPLACEMENT)

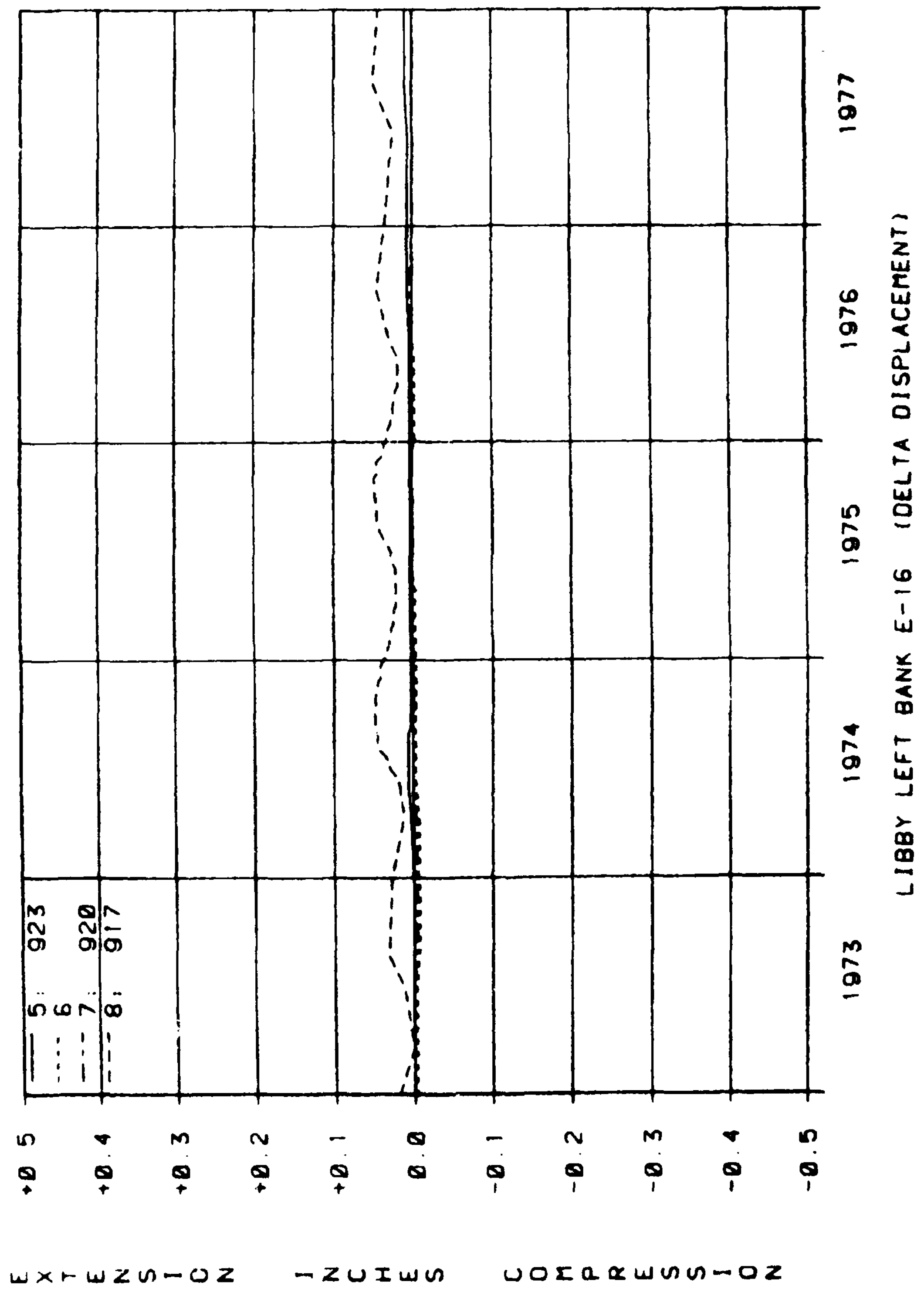

1983
0: TOTAL
1: DIRTY SHAME
2
3: DS + 50
4: DS + 80
5
+0.5
+0.4
+0.3
+0.2
+0.1
0.0
-0.1
-0.2
-0.3
-0.4
-0.5
EXTENSION INCHES COMPRESSION
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC
LIBBY LEFT BANK E-15 (DELTA DISPLACEMENT)

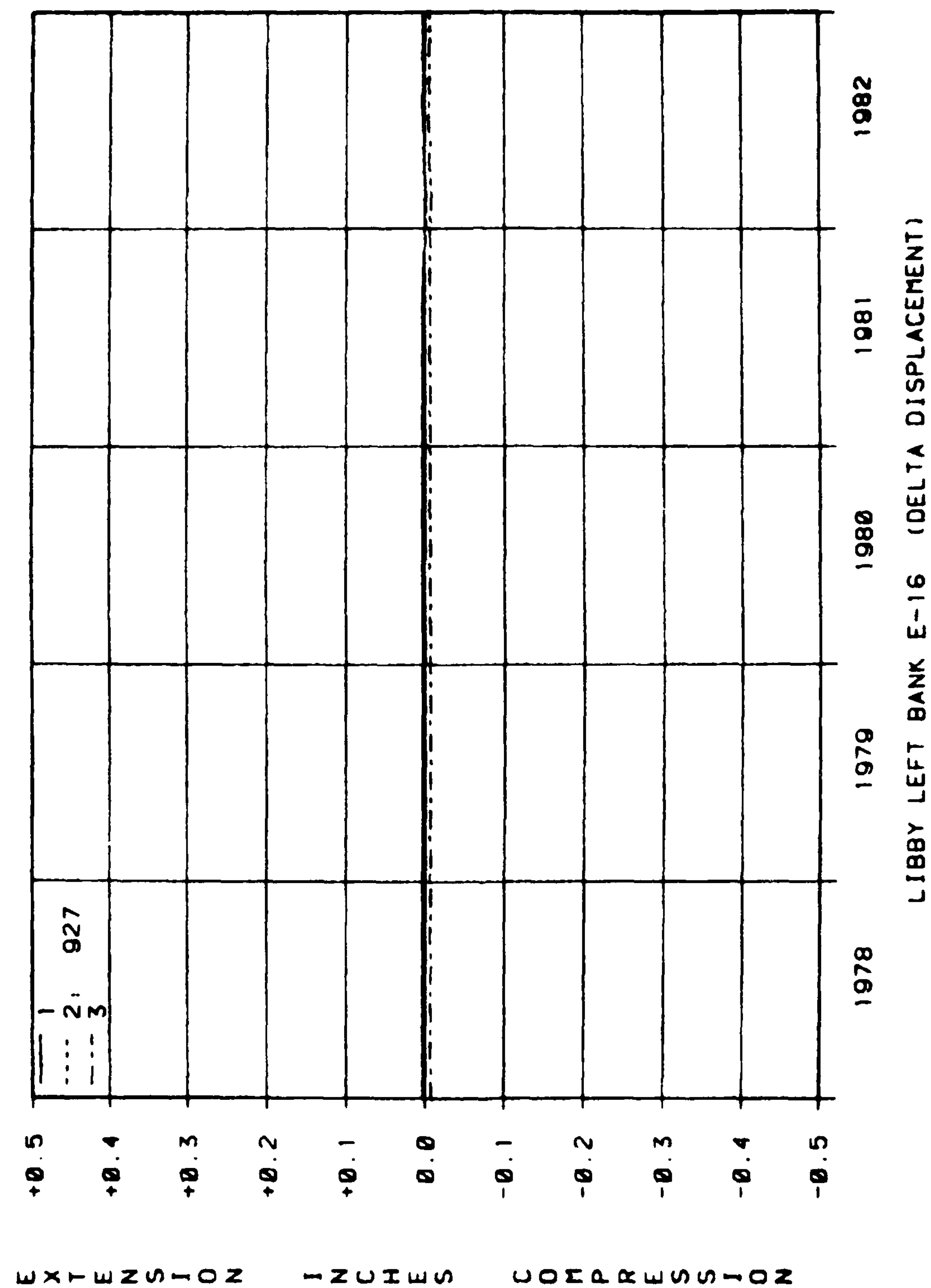

LIBBY LEFT BANK E-16 (DELTA DISPLACEMENT)
EXTENSION INCHES COMPRESSION
+0.5
+0.4
+0.3
+0.2
+0.1
0.0
-0.1
-0.2
-0.3
-0.4
-0.5
1968
1969
1970
1971
1972
1
2: 927
3
4

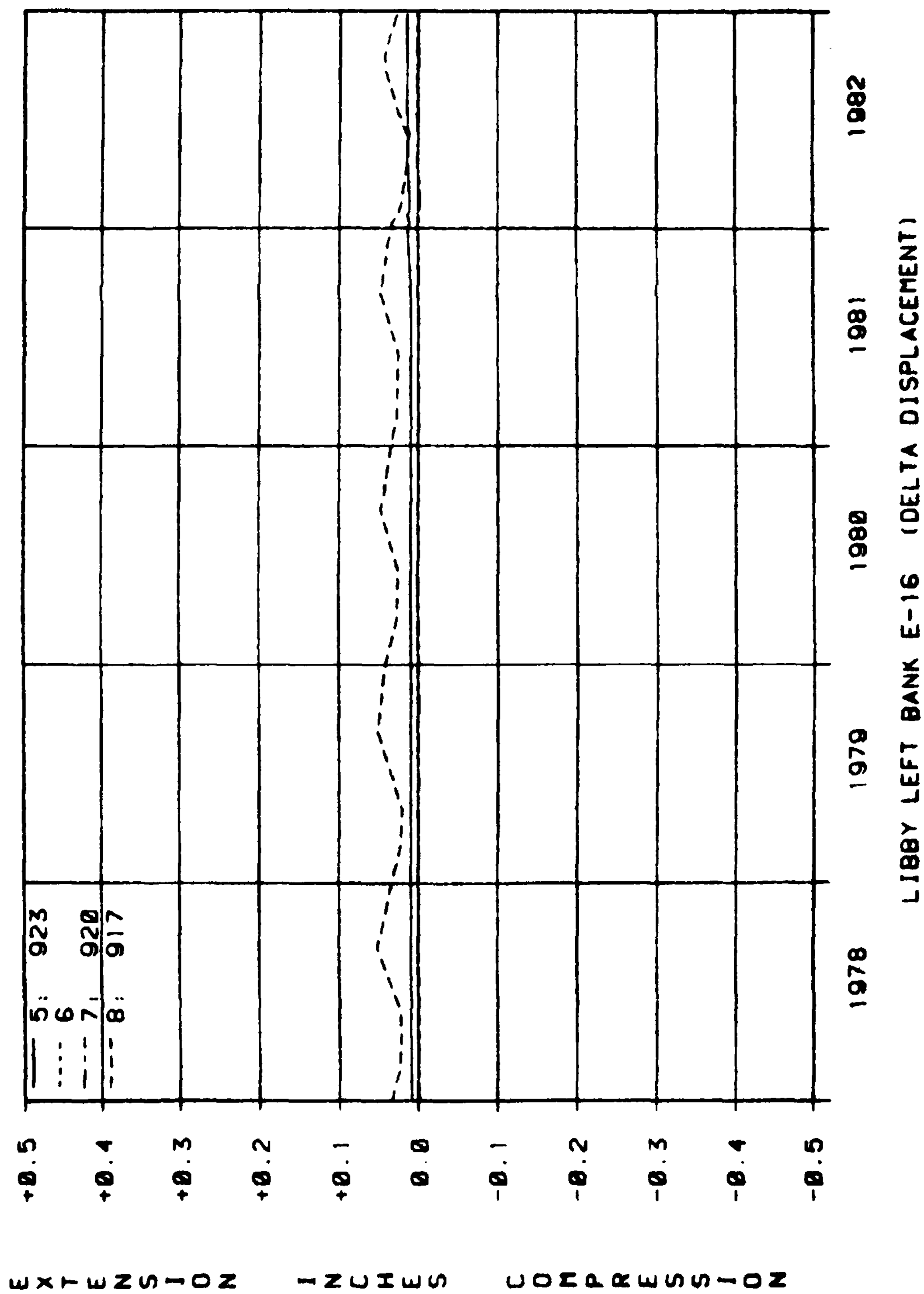


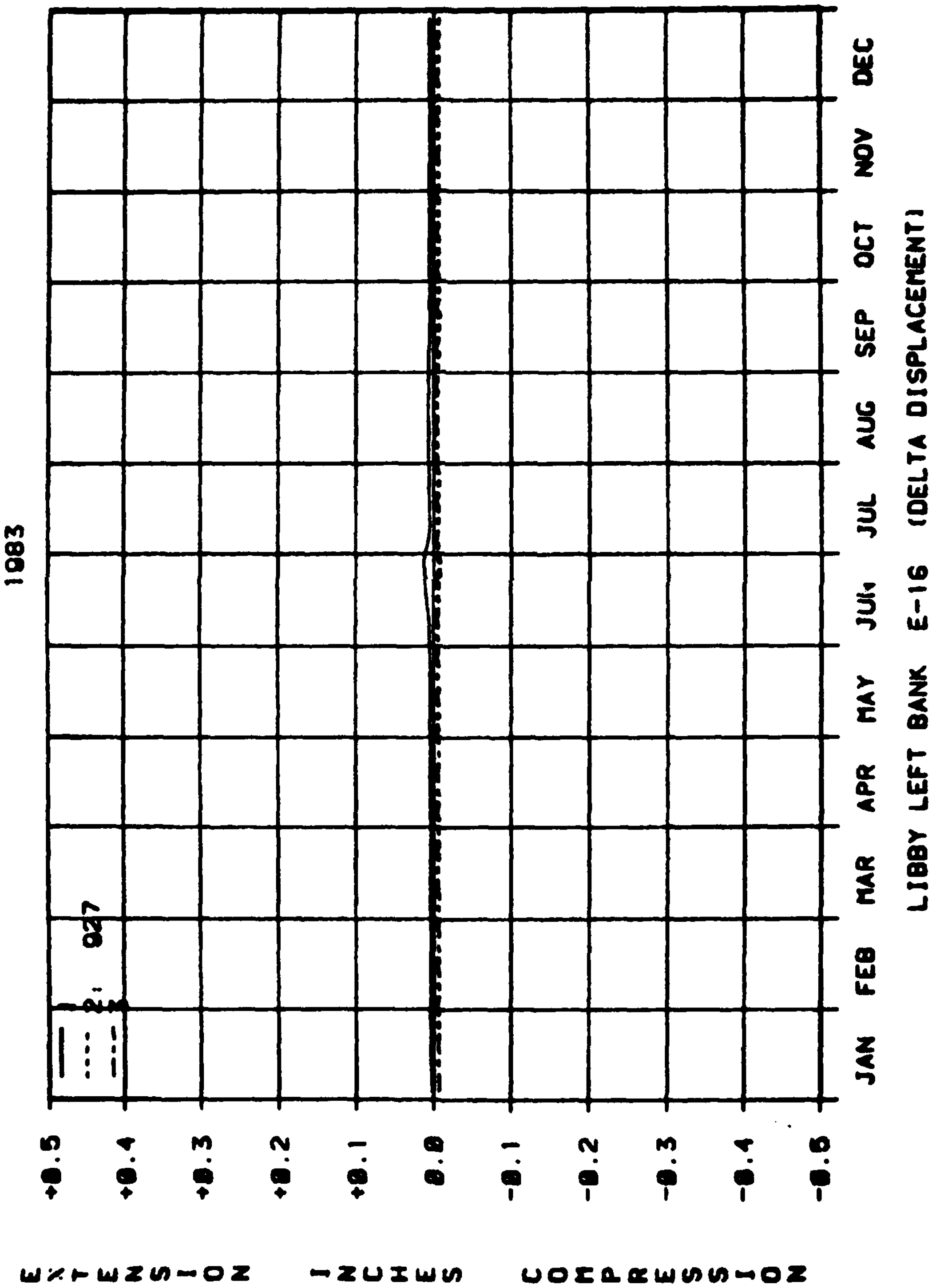
LIBBY LEFT BANK E-16 (DELTA DISPLACEMENT)

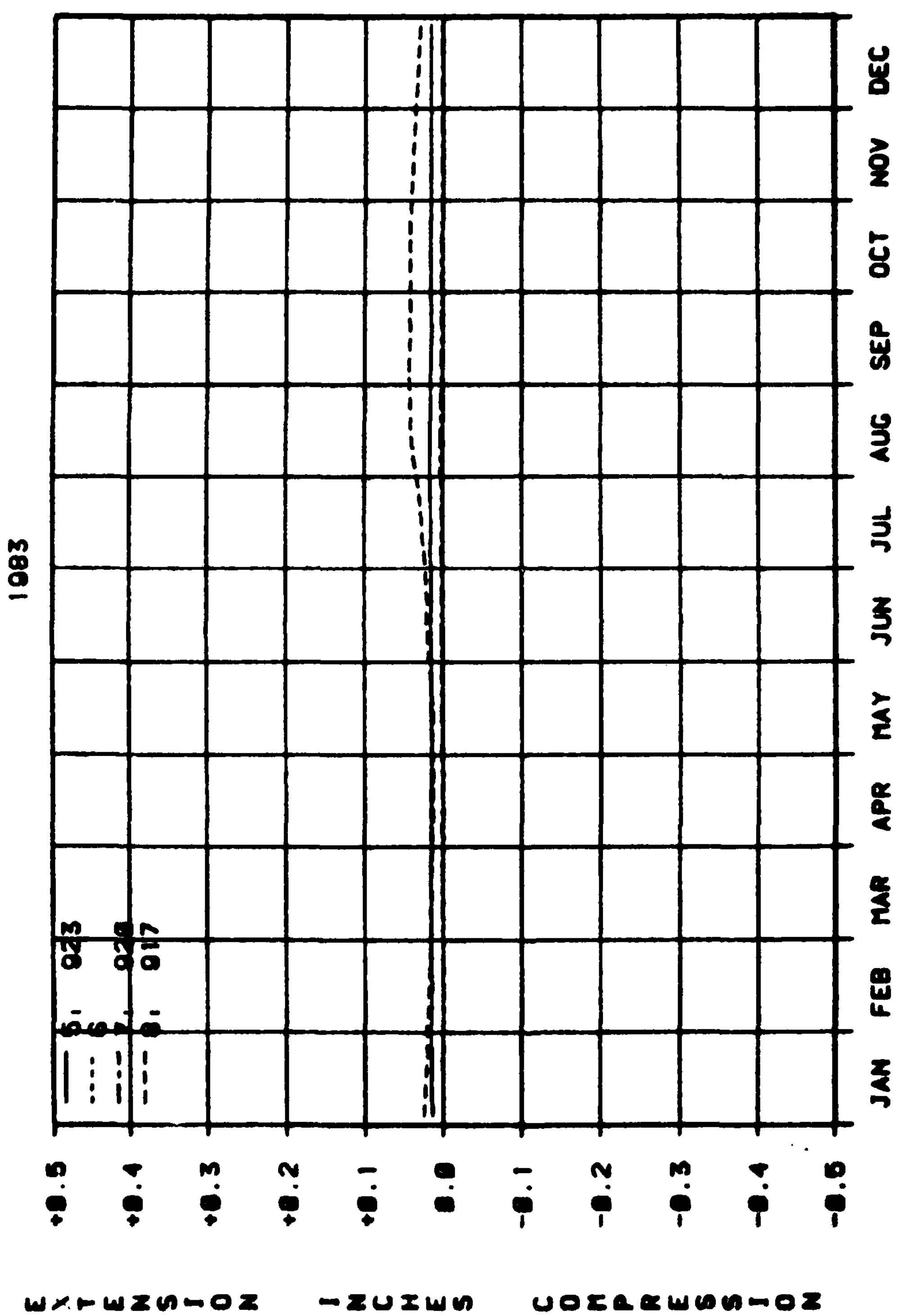

LIBBY LEFT BANK E-16 (DELTA DISPLACEMENT)
1973
1974
1975
1976
1977
+0.5
+0.4
+0.3
+0.2
+0.1
0.0
-0.1
-0.2
-0.3
-0.4
-0.5
EXTENSION INCHES COMPRESSION
1
2: 927
3
4: SENSOR QUIT 6/13/77


LIBBY LEFT BANK E-16 (DELTA DISPLACEMENT)
1973
1974
1975
1976
1977
5: 923
6
7: 920
8: 917
+0.5
+0.4
+0.3
+0.2
+0.1
0.0
-0.1
-0.2
-0.3
-0.4
-0.5
EXTENSION
INCHES
COMPRESSION

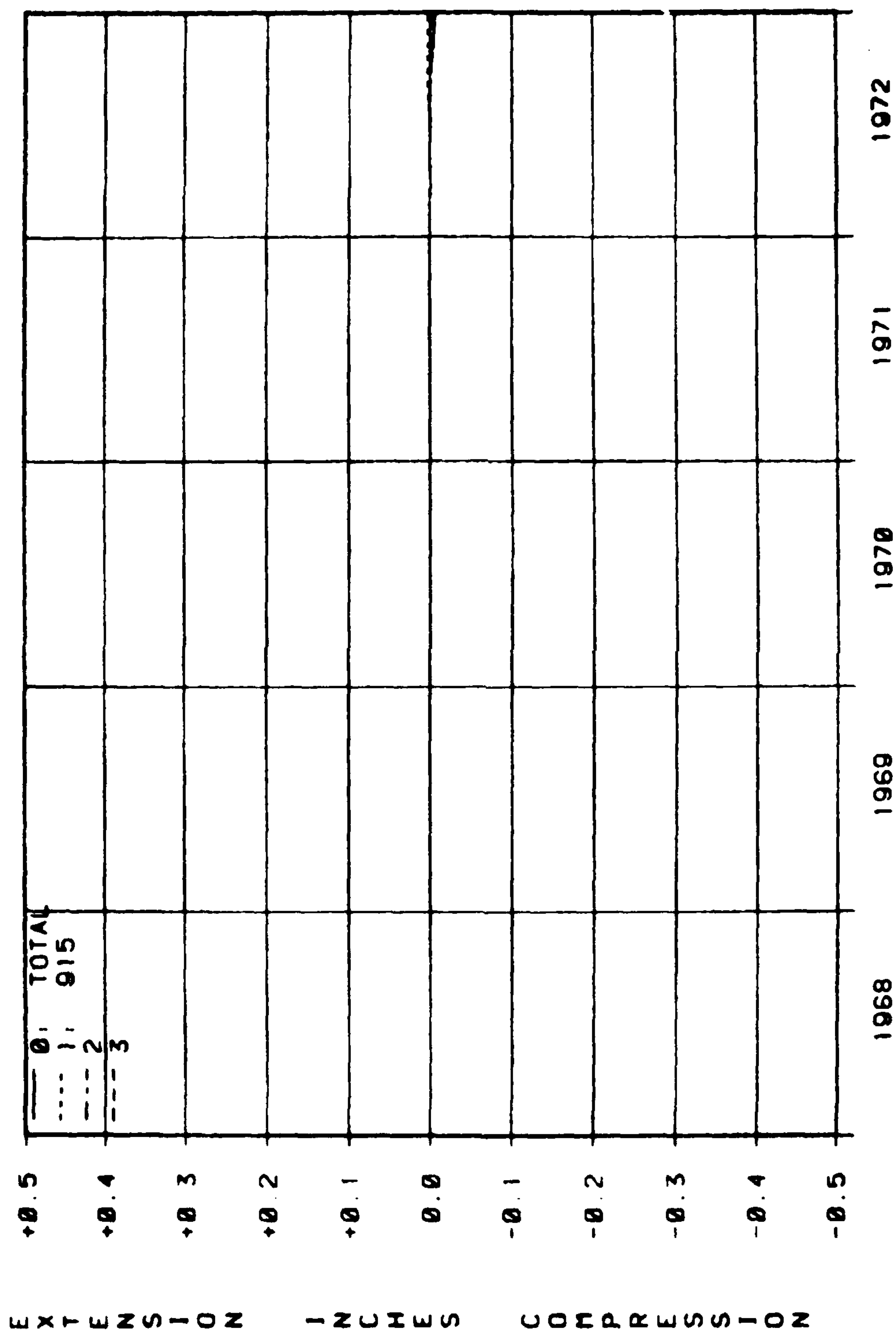

LIBBY LEFT BANK E-16 (DELTA DISPLACEMENT)
1 2 927 3
1978
1979
1980
1981
1982
+0.5
+0.4
+0.3
+0.2
+0.1
0.0
-0.1
-0.2
-0.3
-0.4
-0.5
EXTENSION INCHES COMPRESSION


5: 923
6
7: 920
8: 917
+0.5
+0.4
+0.3
+0.2
+0.1
0.0
-0.1
-0.2
-0.3
-0.4
-0.5
EXTENSION INCHES COMPRESSION
1978
1979
1980
1981
1982
LIBBY LEFT BANK E-16 (DELTA DISPLACEMENT)

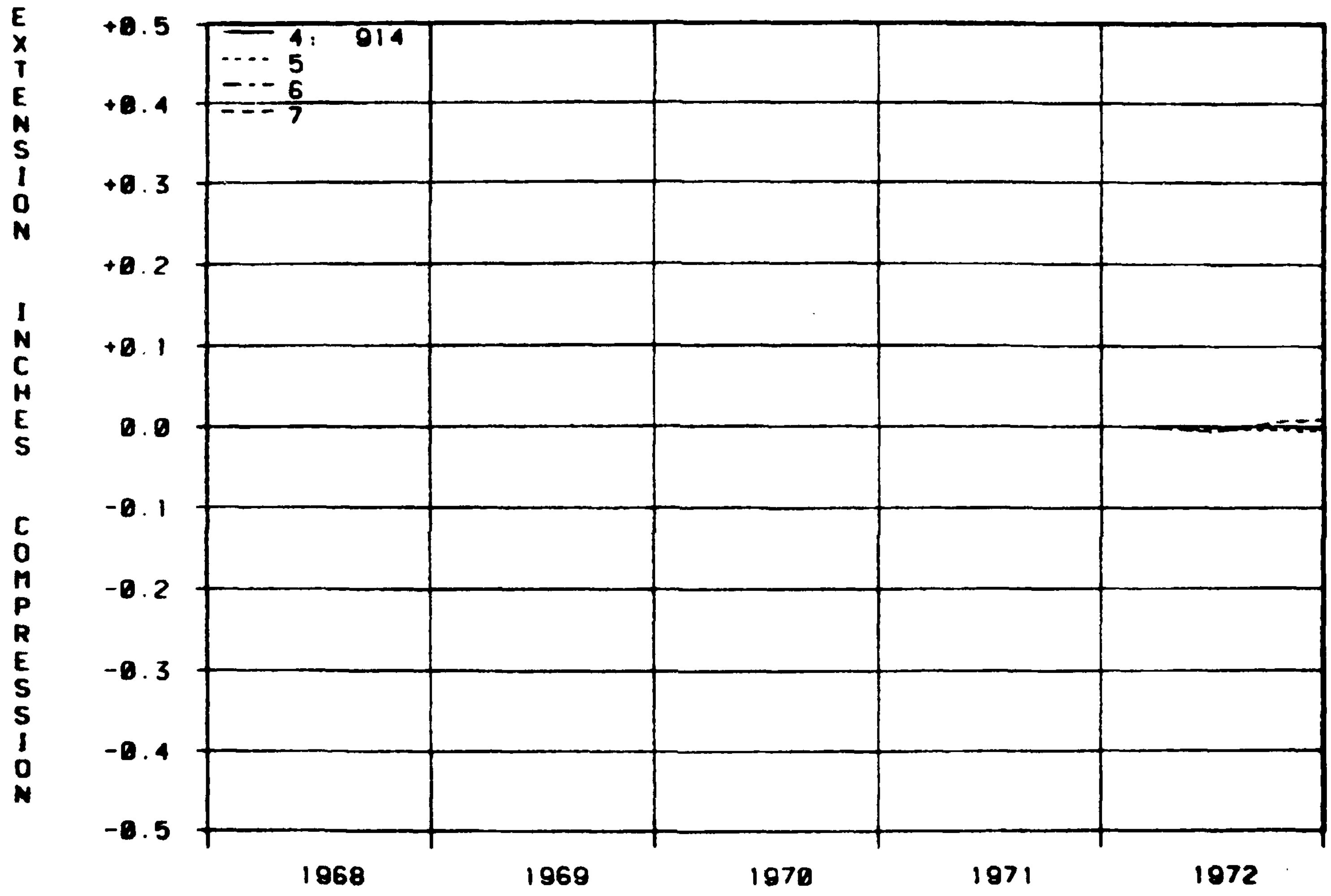

1983
1
2
3
927
+0.5
+0.4
+0.3
+0.2
+0.1
0.0
-0.1
-0.2
-0.3
-0.4
-0.5
EXTENSION INCHES COMPRESSION
JAN FEB MAR APR MAY JUL AUG SEP OCT NOV DEC
LIBBY LEFT BANK E-16 (DELTA DISPLACEMENT)



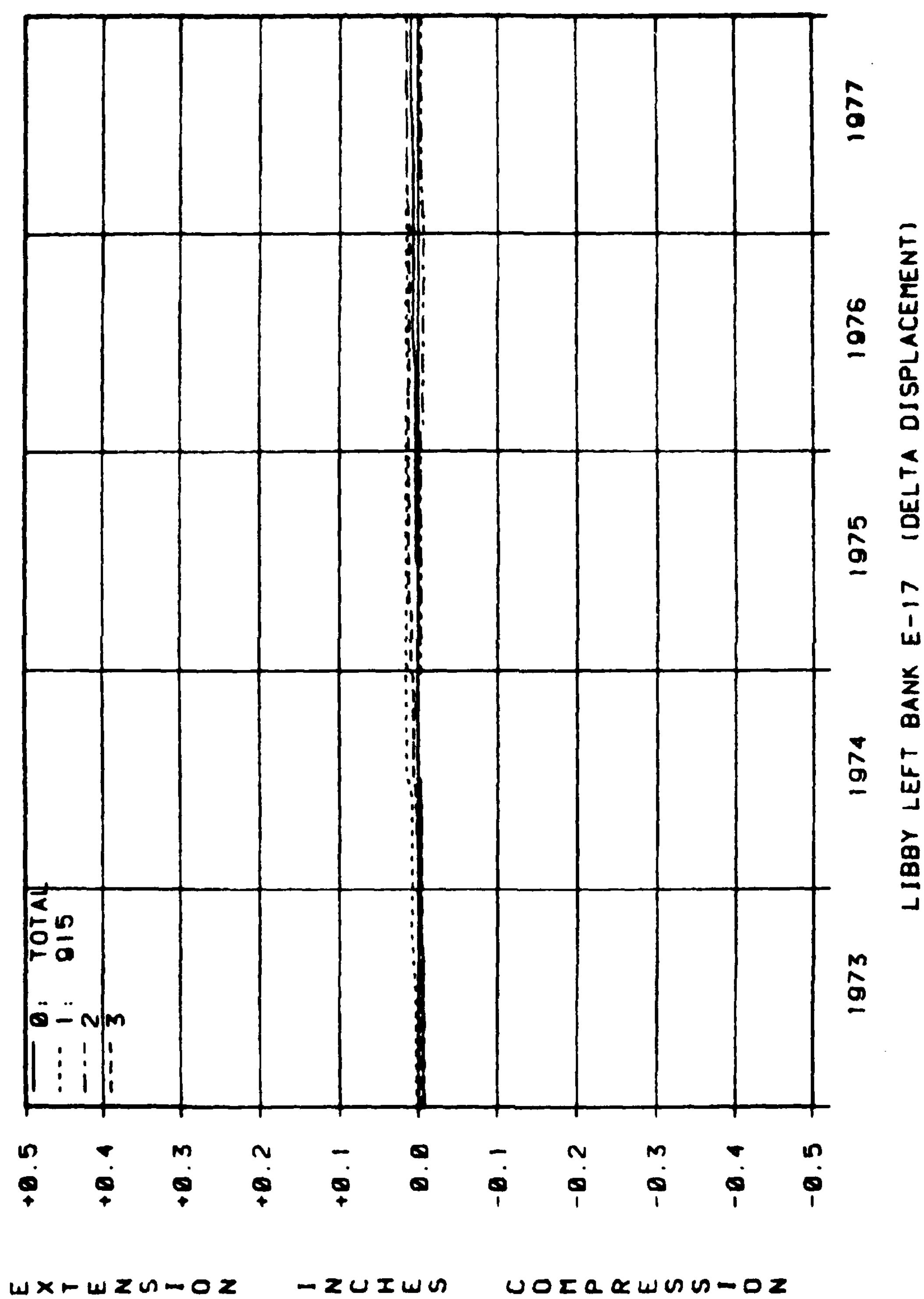
LIBBY LEFT BANK E-16 (DELTA DISPLACEMENT)

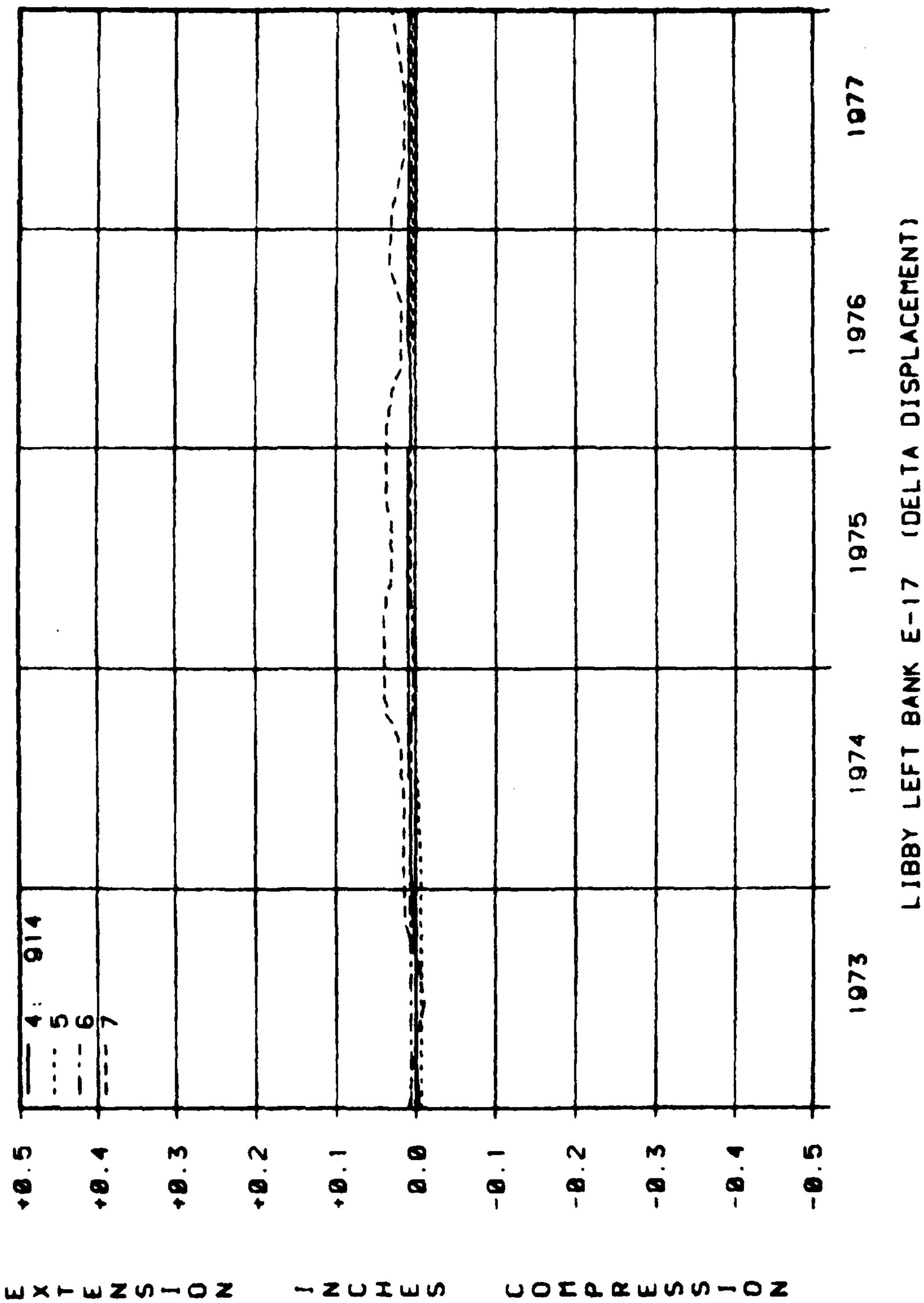


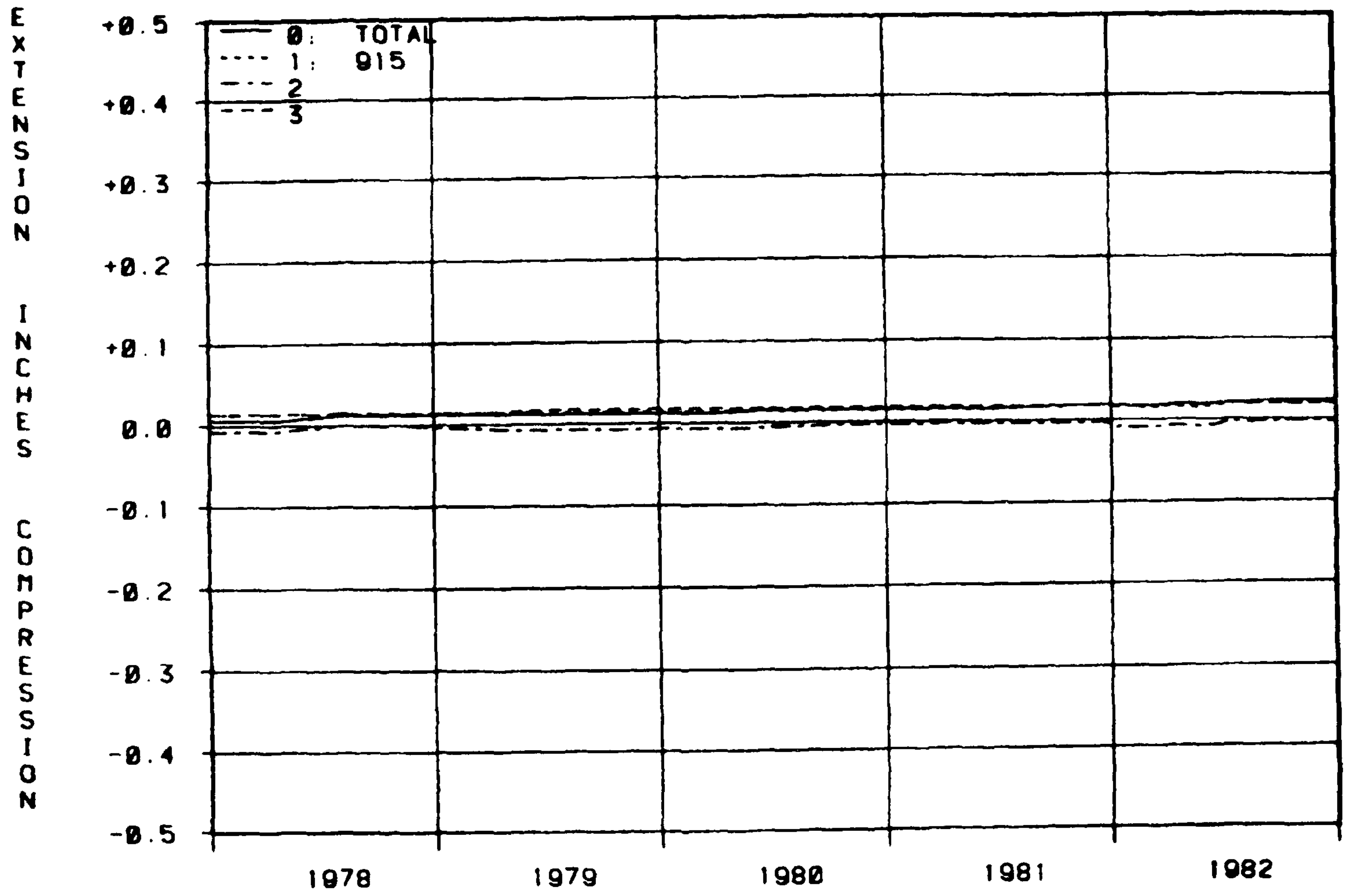
LIBBY LEFT BANK E-17 (DELTA DISPLACEMENT)



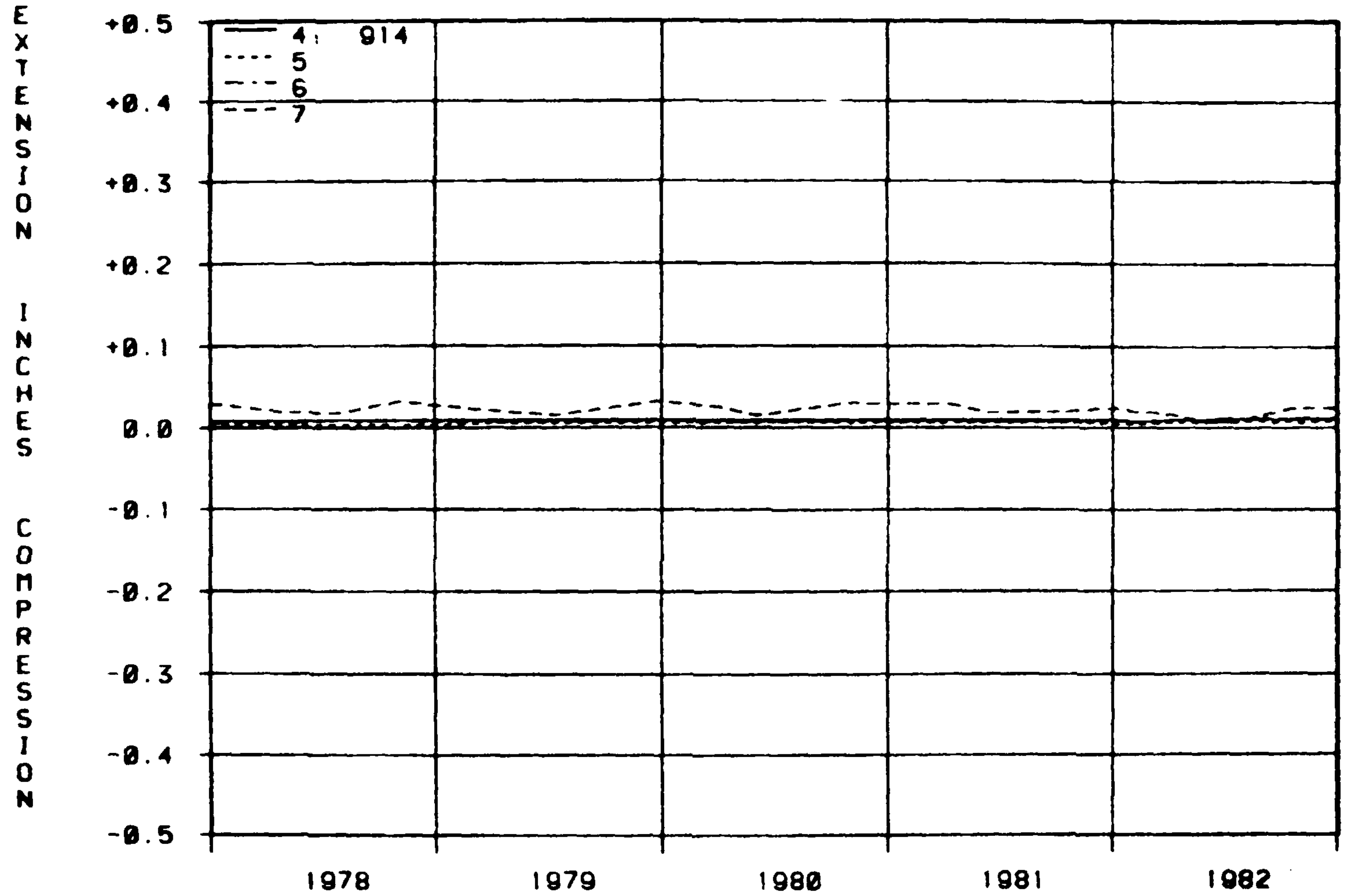
LIBBY LEFT BANK E-17 (DELTA DISPLACEMENT)


LIBBY LEFT BANK E-17 (DELTA DISPLACEMENT)
EXTENSION INCHES COMPRESSION
+0.5
+0.4
+0.3
+0.2
+0.1
0.0
-0.1
-0.2
-0.3
-0.4
-0.5
1973
1974
1975
1976
1977
0: TOTAL
1: 915
2
3

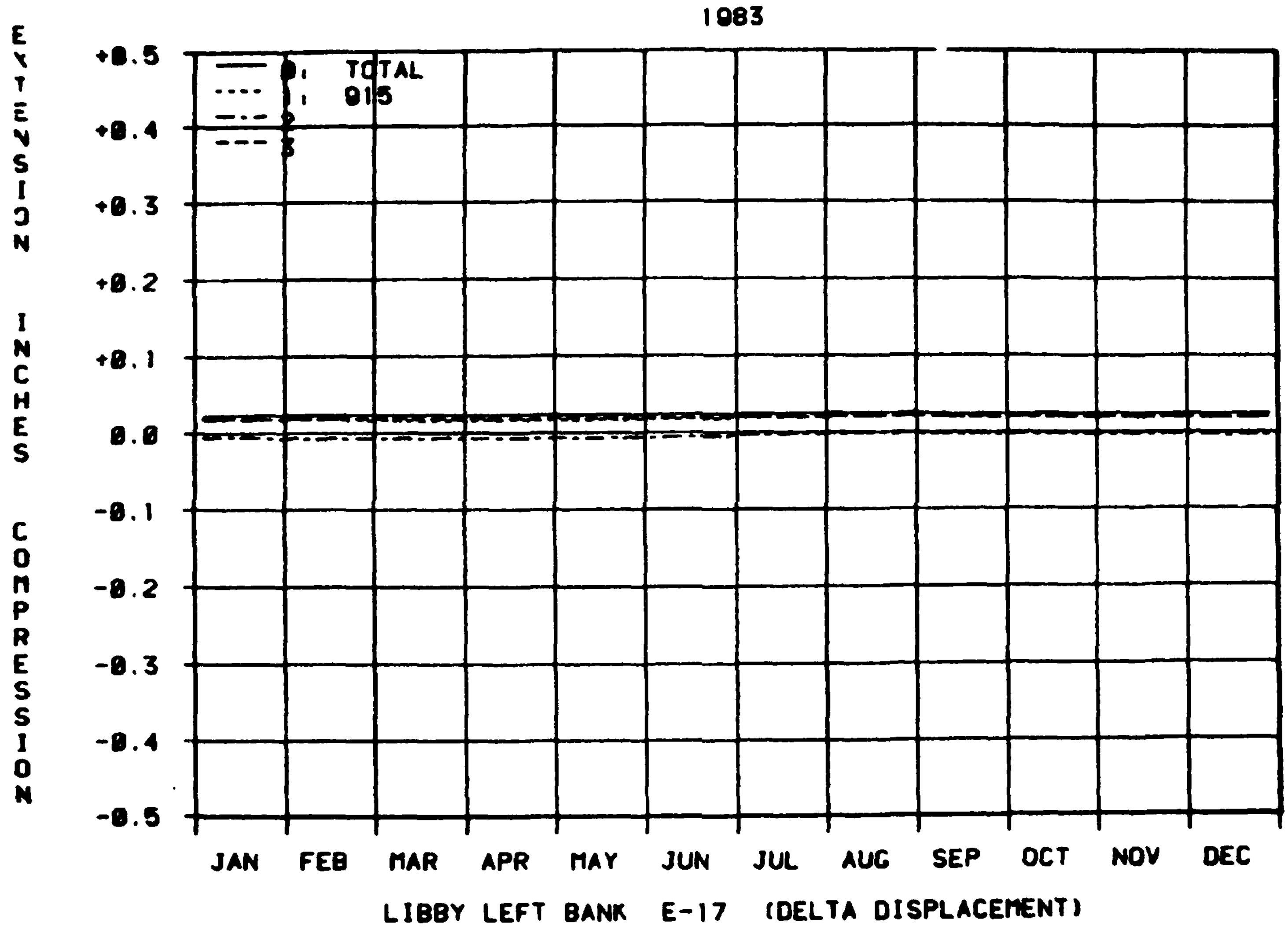

LIBBY LEFT BANK E-17 (DELTA DISPLACEMENT)
1973
1974
1975
1976
1977
4: 914
5
6
7
+0.5
+0.4
+0.3
+0.2
+0.1
0.0
-0.1
-0.2
-0.3
-0.4
-0.5
EXTENSION INCHES COMPRESSION



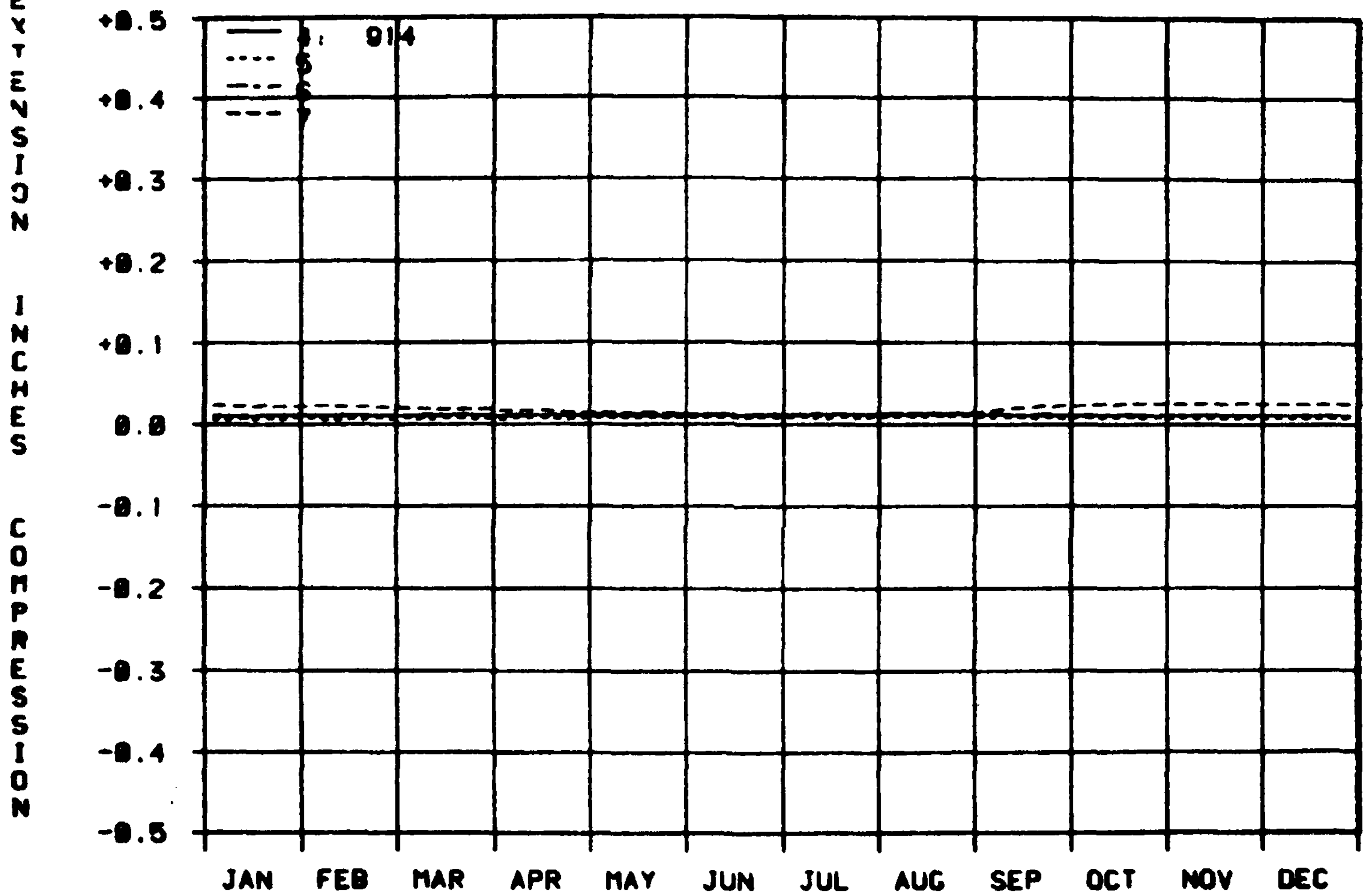
LIBBY LEFT BANK E-17 (DELTA DISPLACEMENT)



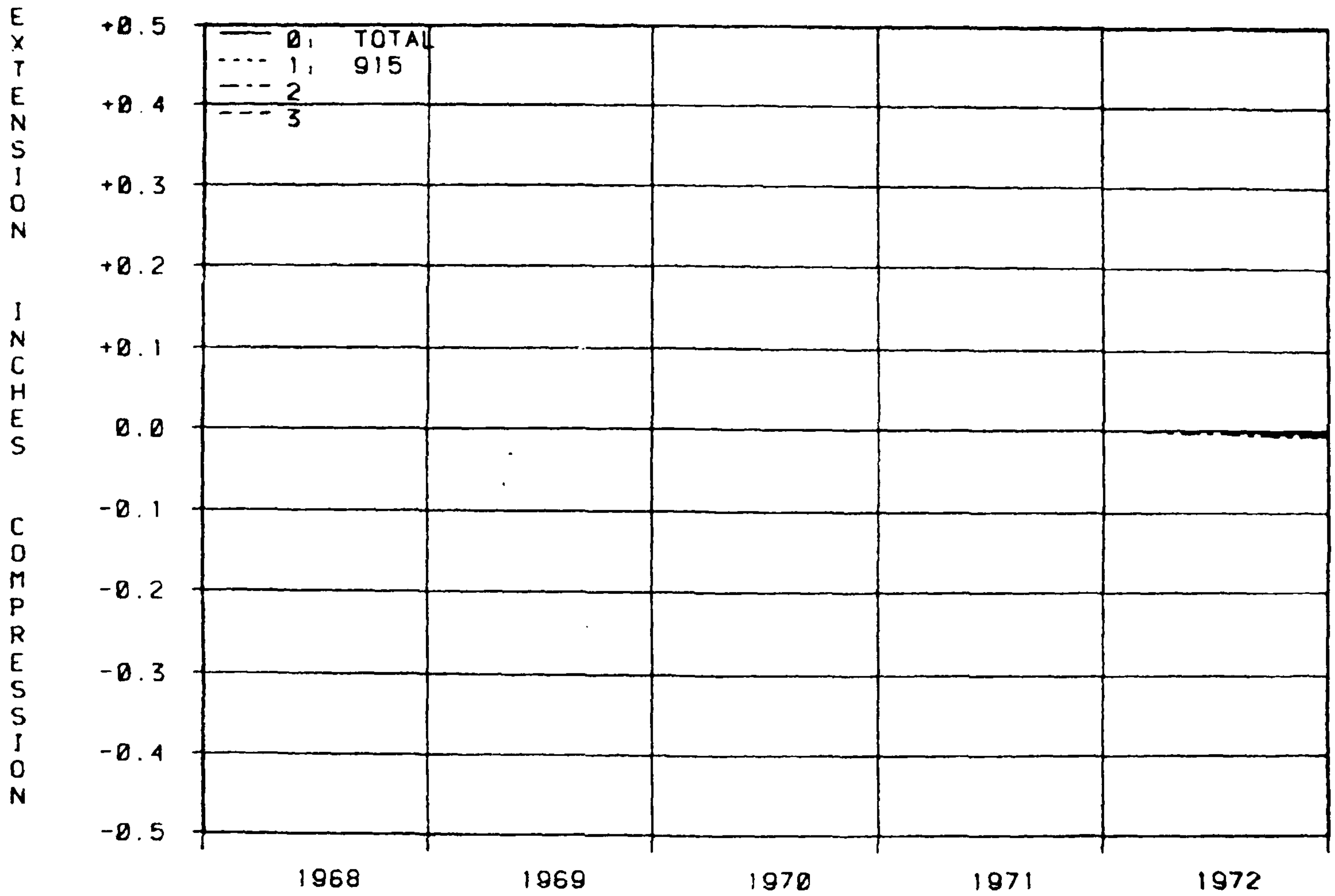
LIBBY LEFT BANK E-17 (DELTA DISPLACEMENT)


1983
0: TOTAL
1: 915
2
3
EXTENSION INCHES COMPRESSION
+0.5
+0.4
+0.3
+0.2
+0.1
0.0
-0.1
-0.2
-0.3
-0.4
-0.5
JAN FEB MAR APR MAY JUN JUL AUG SEP OCT NOV DEC
LIBBY LEFT BANK E-17 (DELTA DISPLACEMENT)

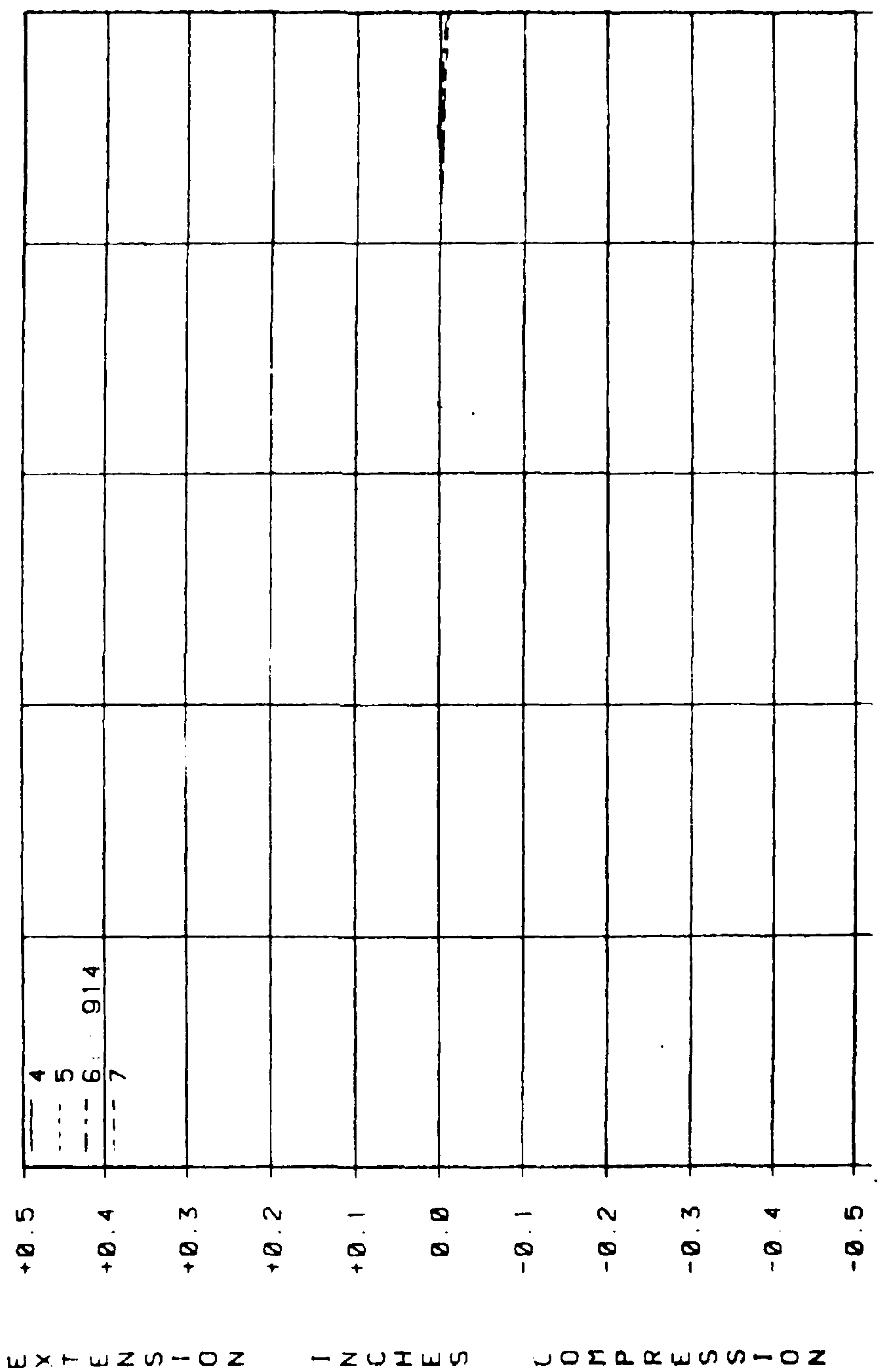
1983



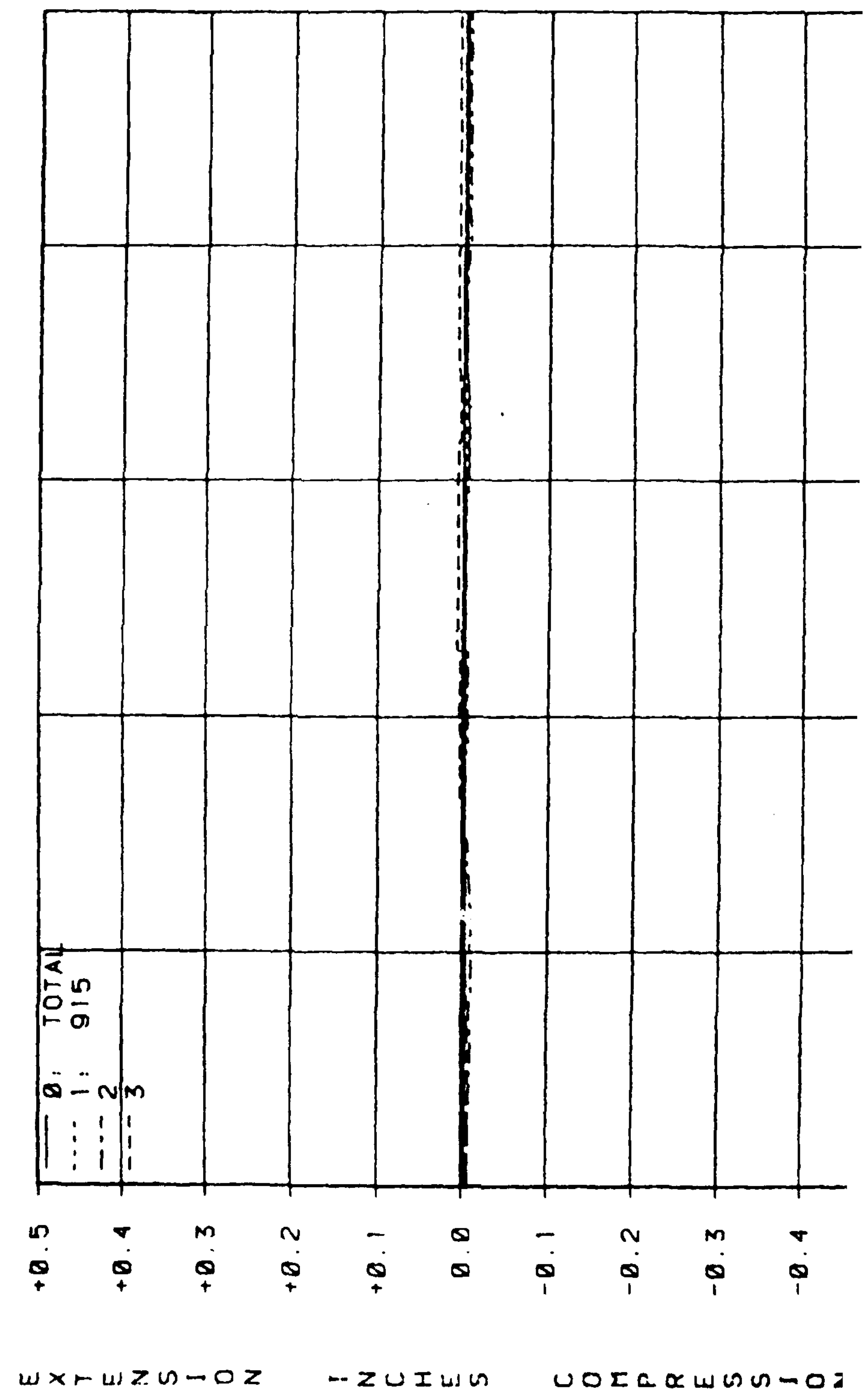
LIBBY LEFT BANK E-17 (DELTA DISPLACEMENT)

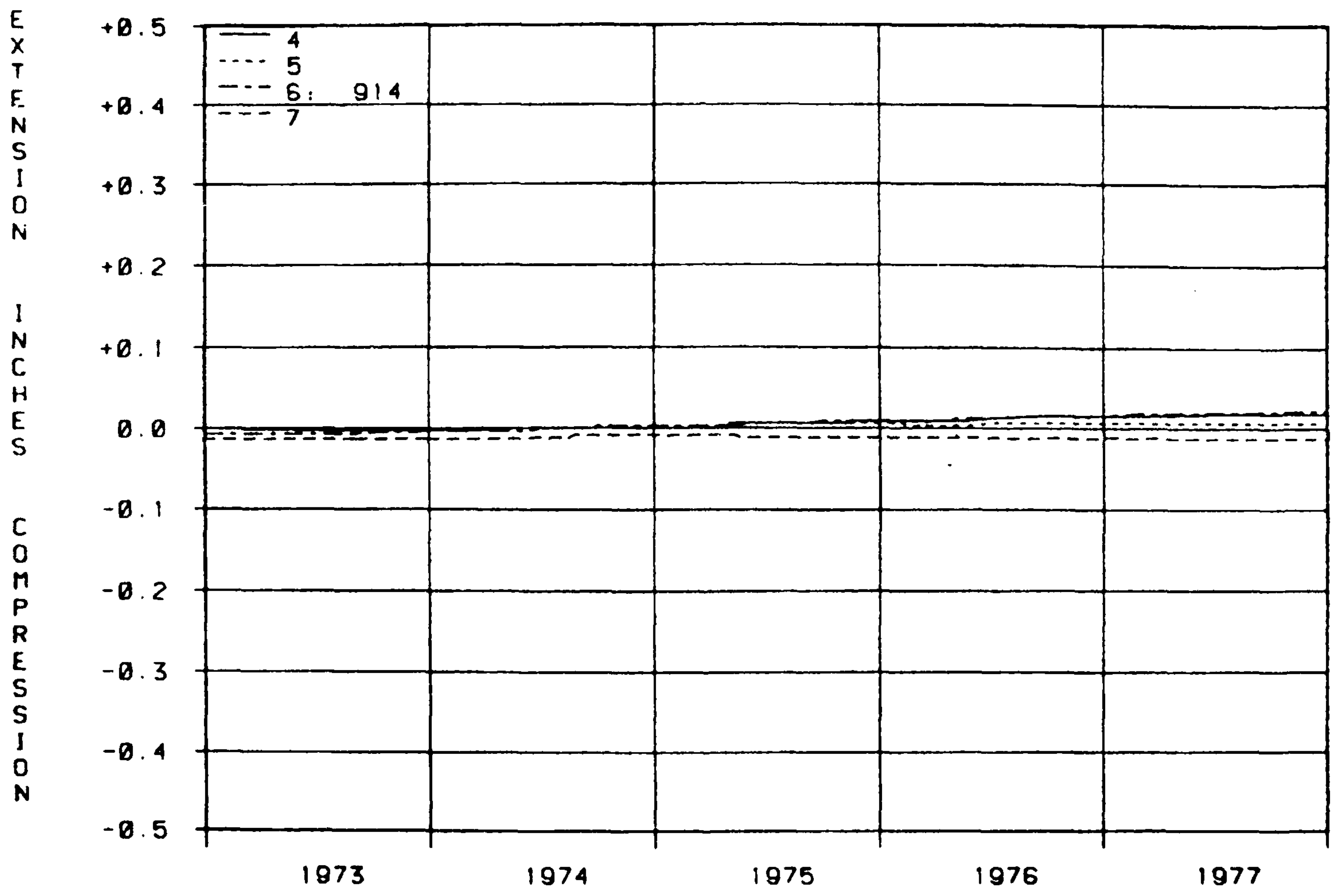


LIBBY LEFT BANK E-18 (DELTA DISPLACEMENT)

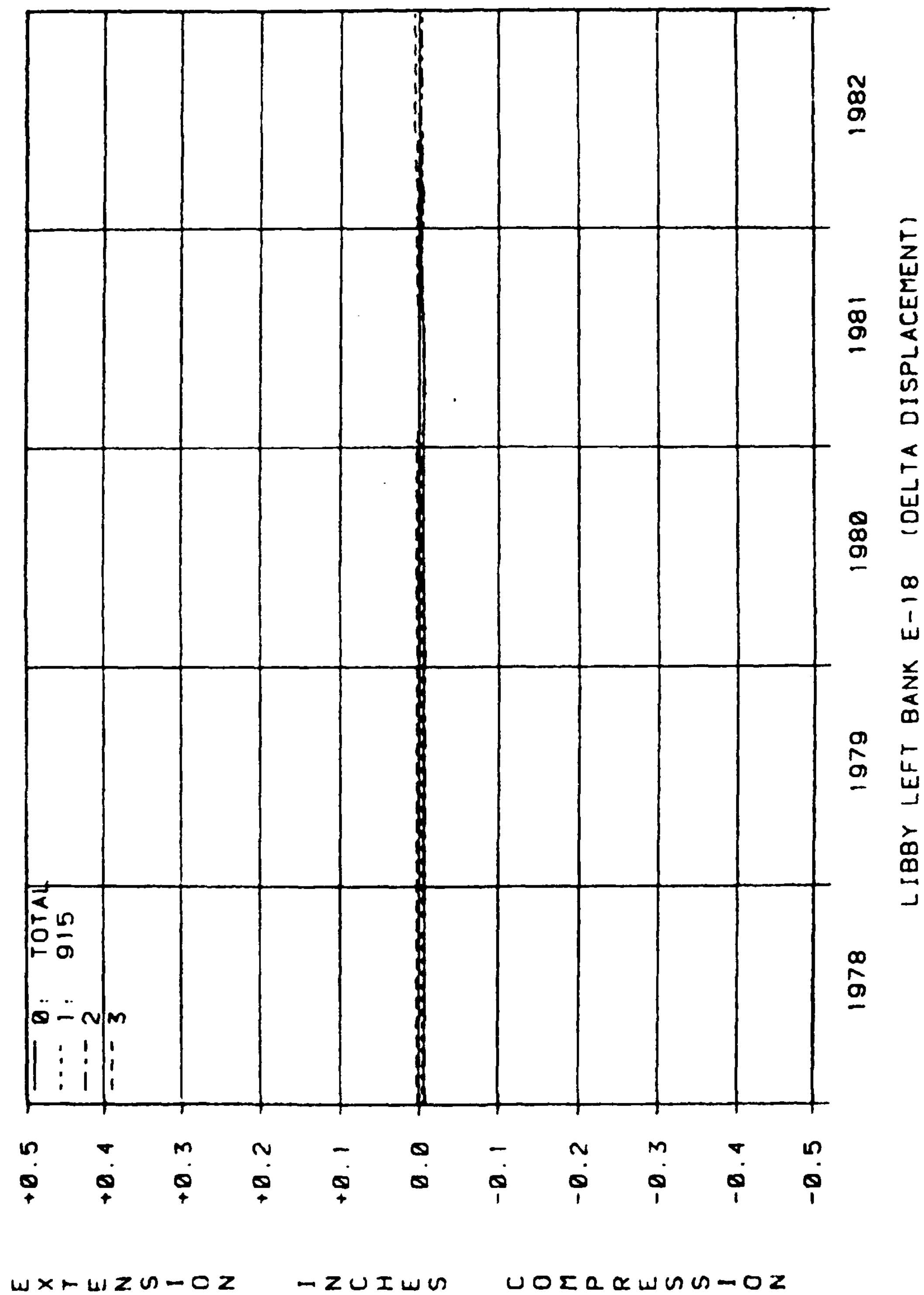


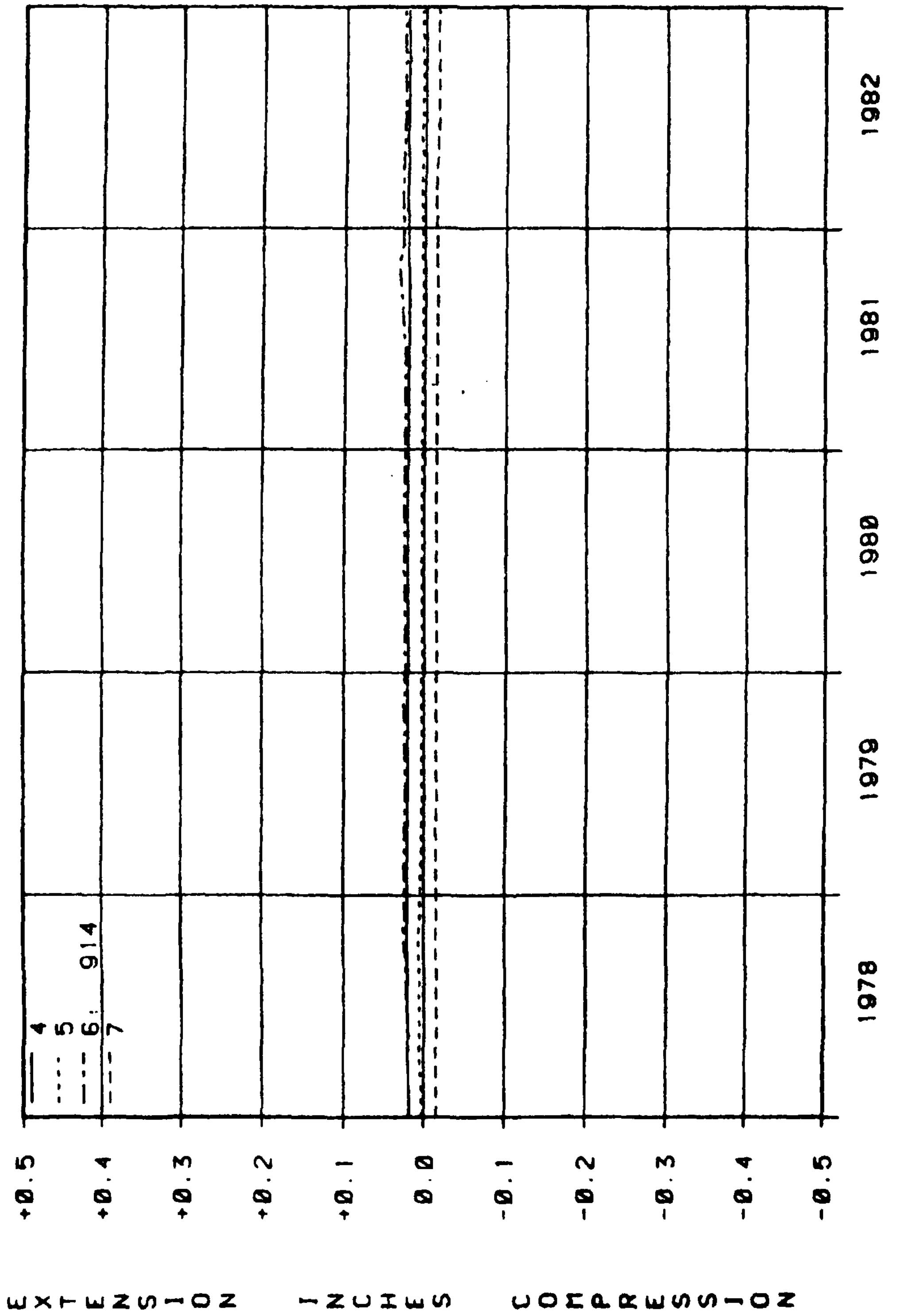
4
5
6
7
914
+0.5
+0.4
+0.3
+0.2
+0.1
0.0
-0.1
-0.2
-0.3
-0.4
-0.5
EXTENSION INCHES COMPRESSION


Ø: TOTAL
1: 915
2
3
+Ø.5
+Ø.4
+Ø.3
+Ø.2
+Ø.1
Ø.Ø
-Ø.1
-Ø.2
-Ø.3
-Ø.4
EXTENSION
INCHES
COMPRESSION

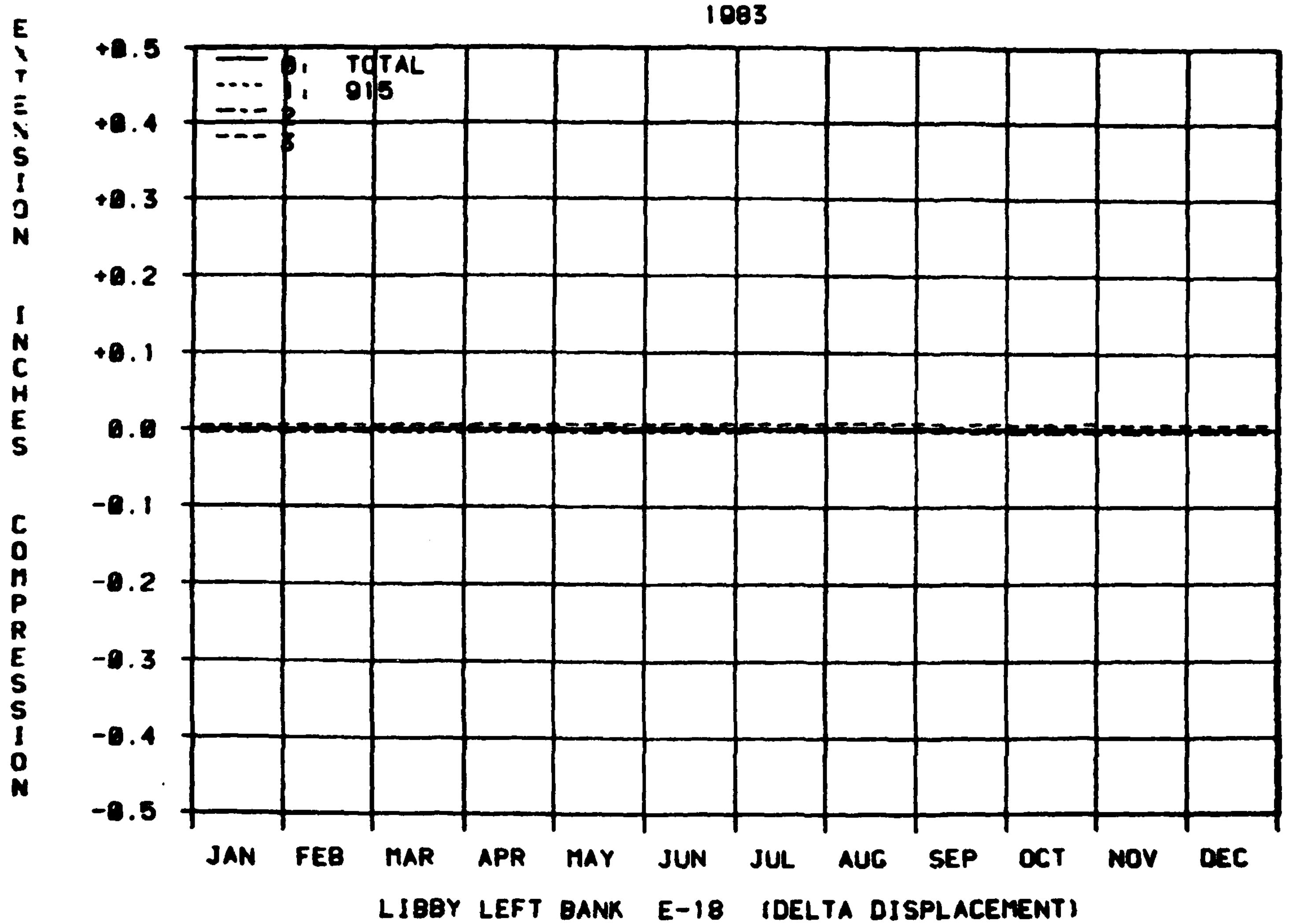


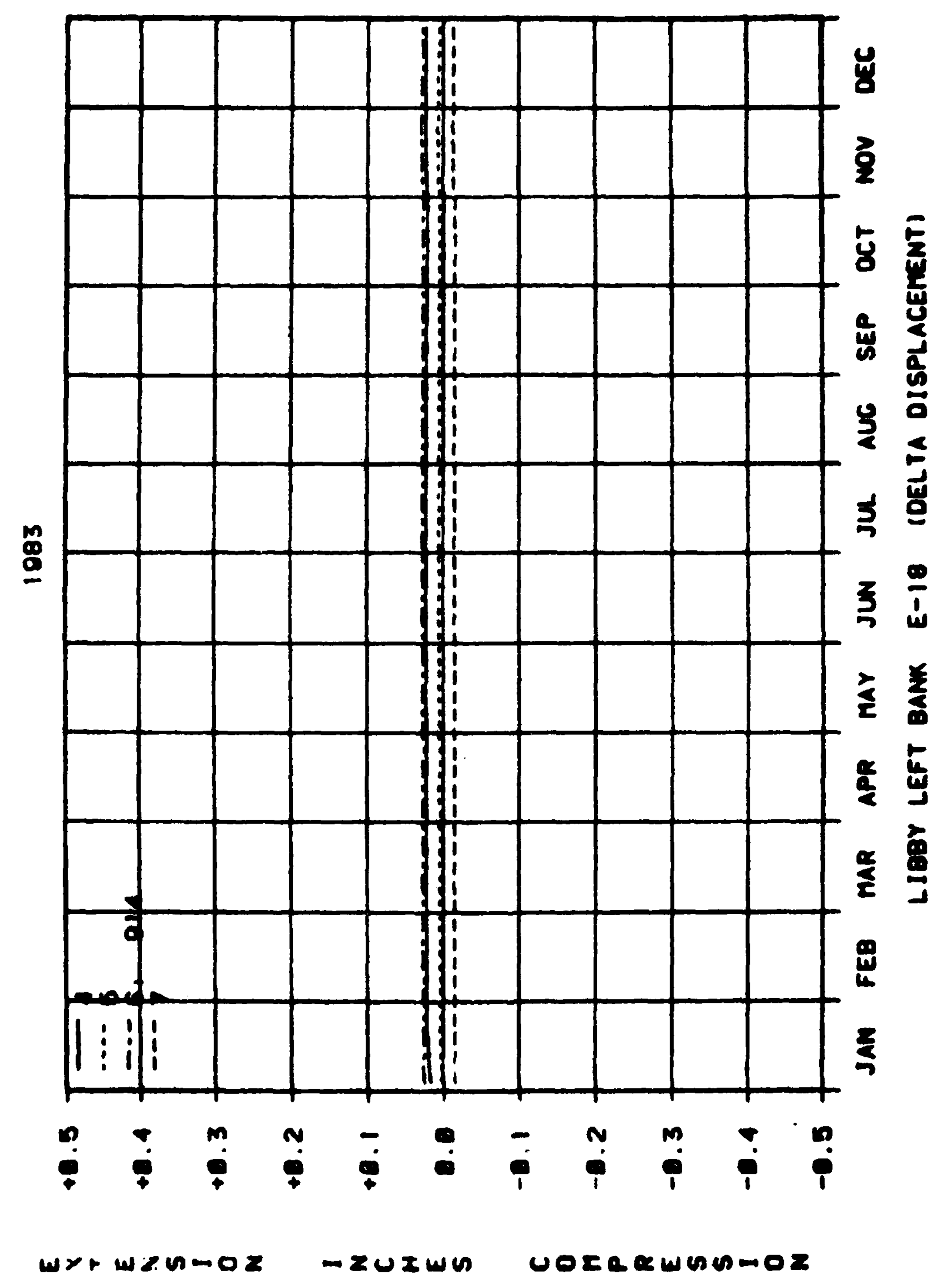
LIBBY LEFT BANK E-18 (DELTA DISPLACEMENT)


0: TOTAL
1: 915
2
3
1978
1979
1980
1981
1982
LIBBY LEFT BANK E-18 (DELTA DISPLACEMENT)
+0.5
+0.4
+0.3
+0.2
+0.1
0.0
-0.1
-0.2
-0.3
-0.4
-0.5
EXTENSION INCHES COMPRESSION

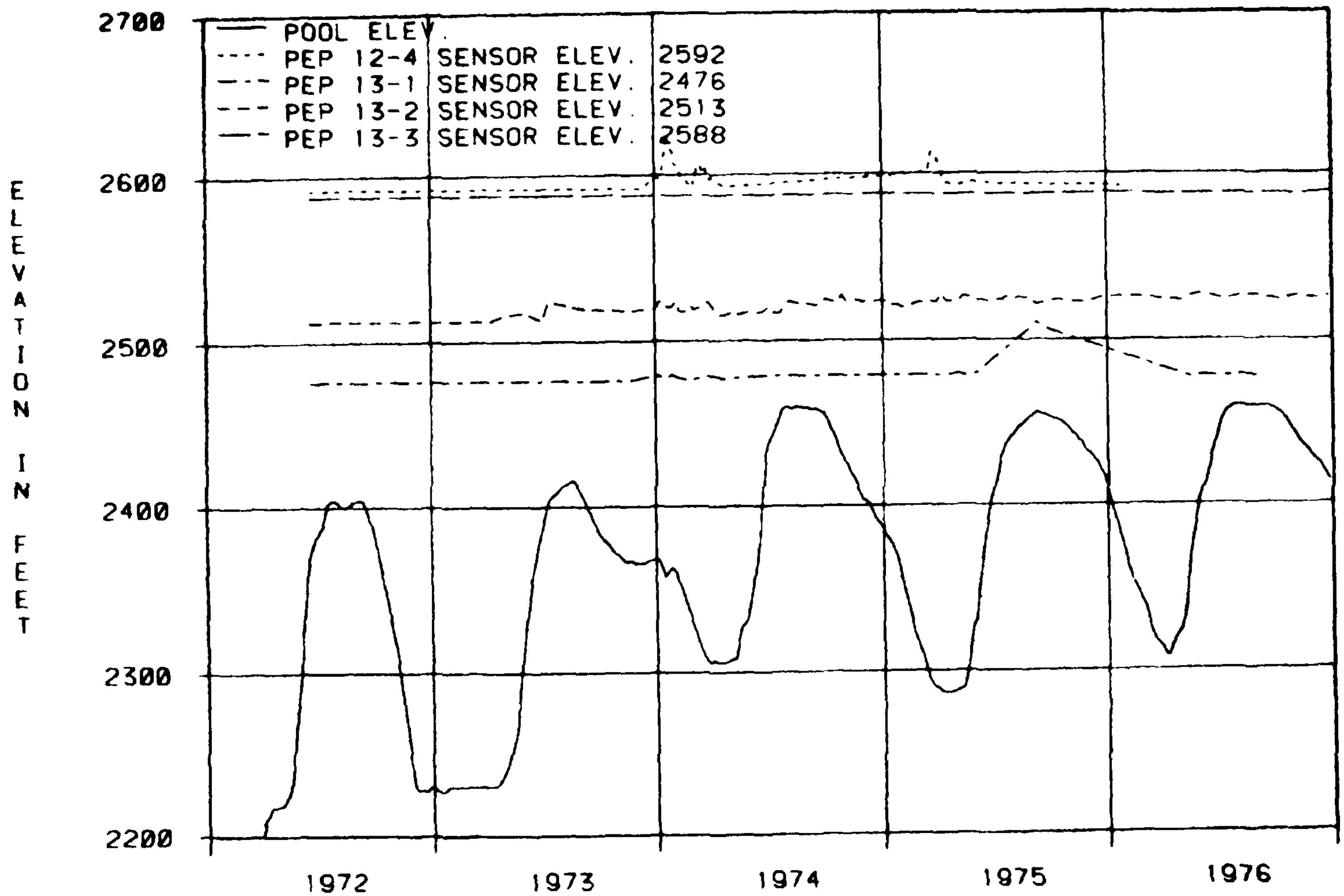


LIBBY LEFT BANK E-18 (DELTA DISPLACEMENT)

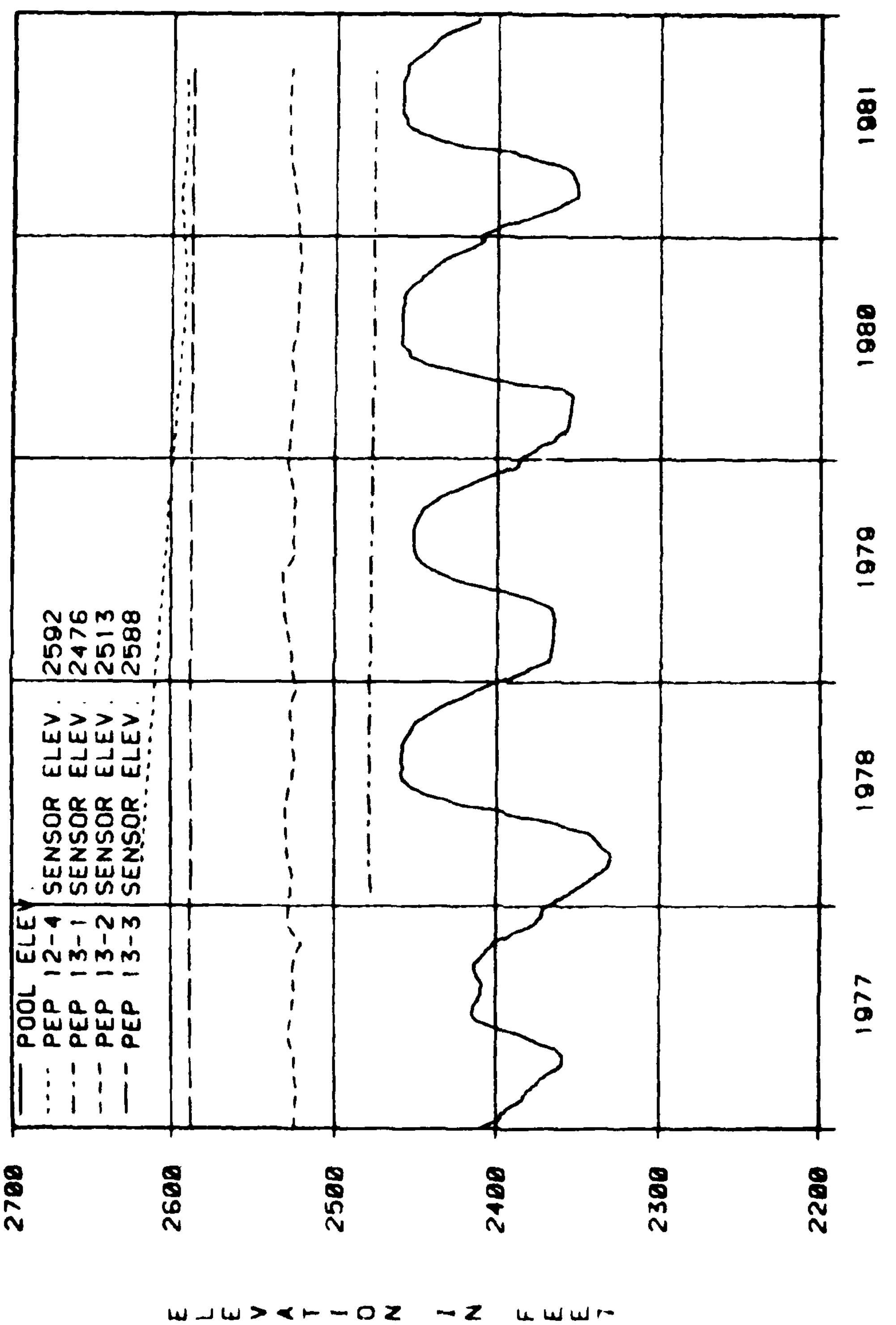

1983
0: TOTAL
1: 915
2
3
EXTENSION INCHES COMPRESSION
+0.5
+0.4
+0.3
+0.2
+0.1
0.0
-0.1
-0.2
-0.3
-0.4
-0.5
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC
LIBBY LEFT BANK E-18 (DELTA DISPLACEMENT)


1983
LIBBY LEFT BANK E-18 (DELTA DISPLACEMENT)
JAN FEB MAR APR MAY JUN JUL AUG SEP OCT NOV DEC
+0.5 +0.4 +0.3 +0.2 +0.1 0.0 -0.1 -0.2 -0.3 -0.4 -0.5
EXTENSION INCHES COMPRESSION

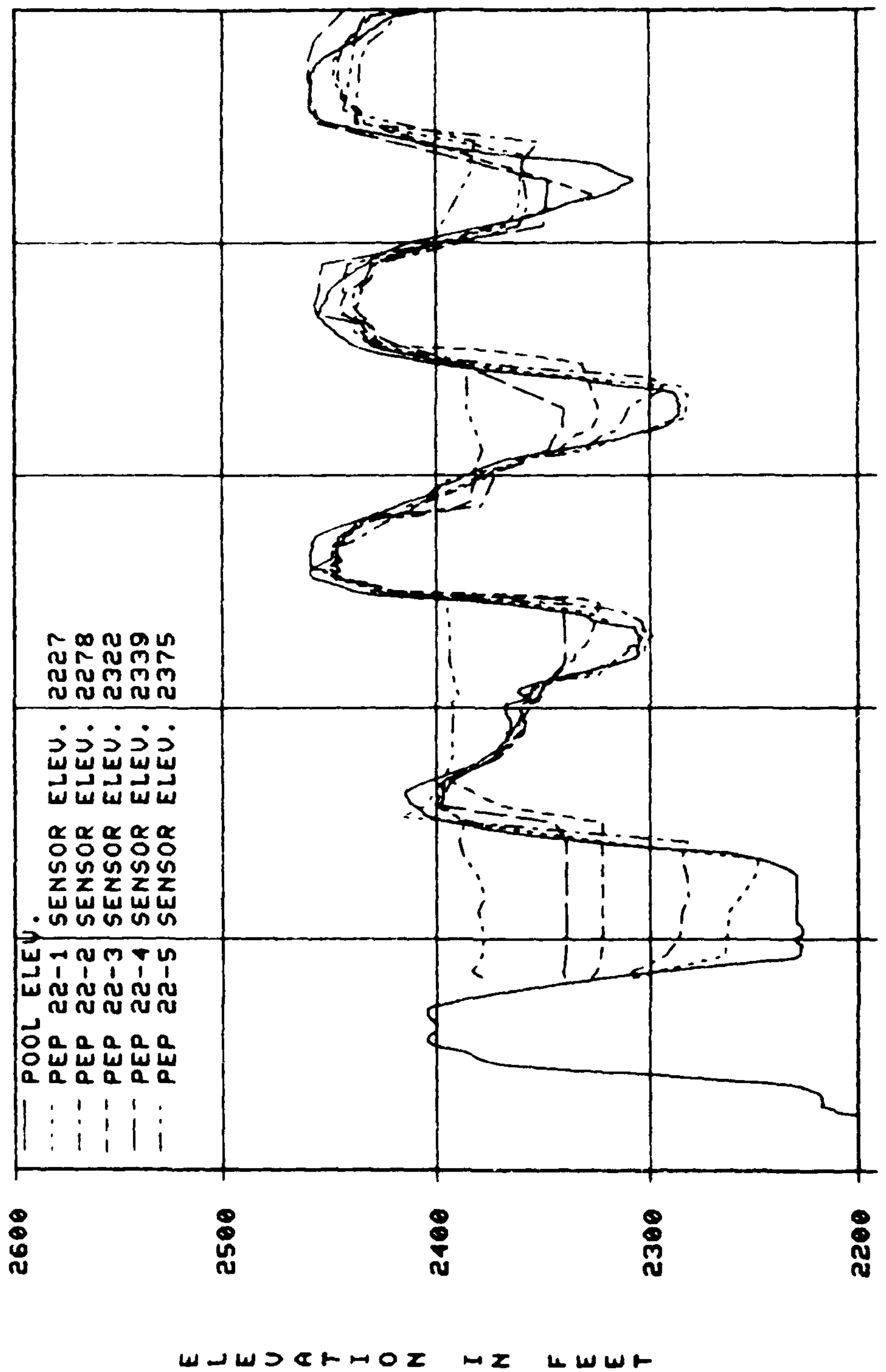
Appendix D - Piezometer Plots



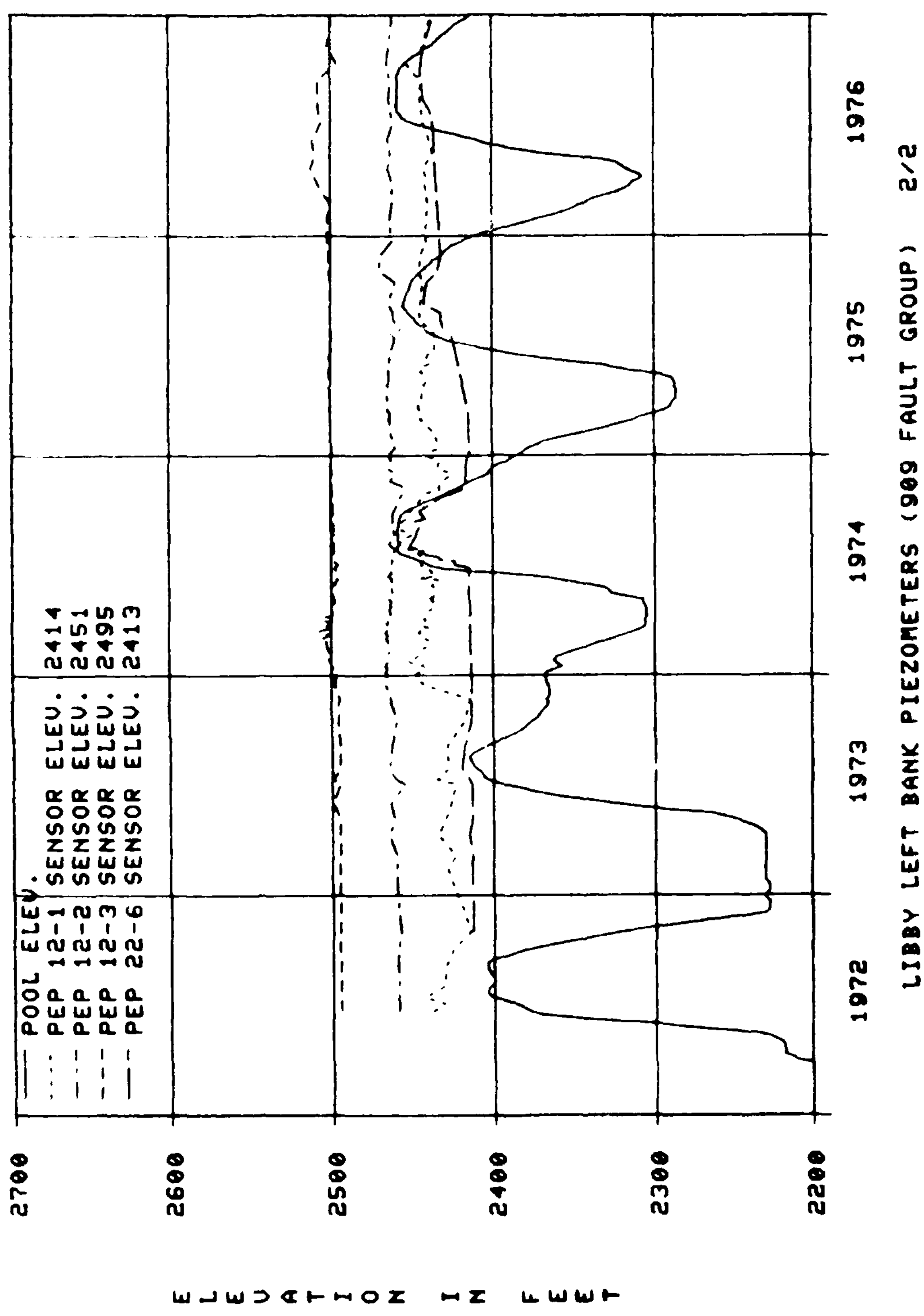
LIBBY LEFT BANK PIEZOMETERS (DS+80 & DS FAULT GROUP)



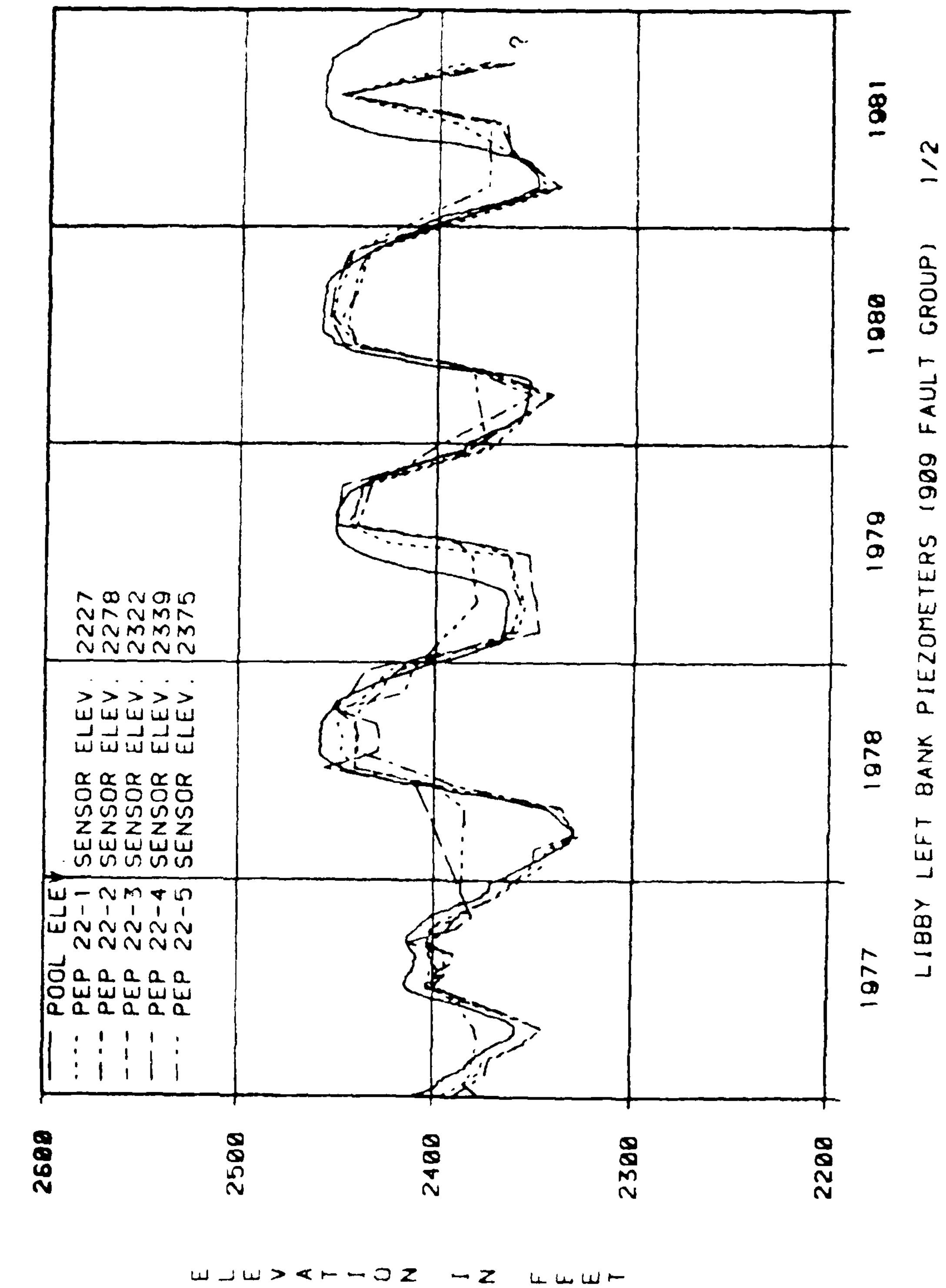
LIBBY LEFT BANK PIEZOMETERS (DS+80 & DS FAULT GROUP)

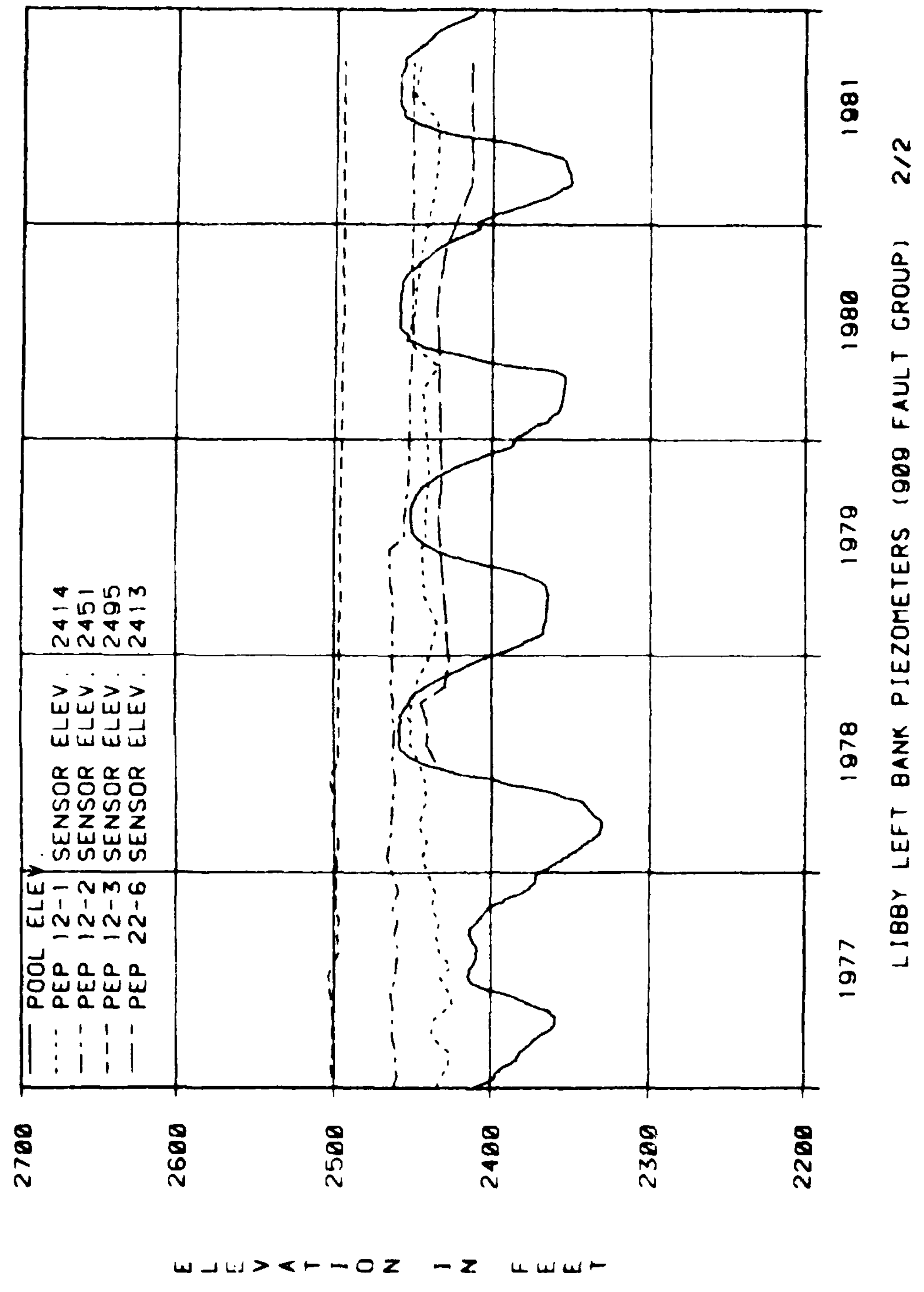


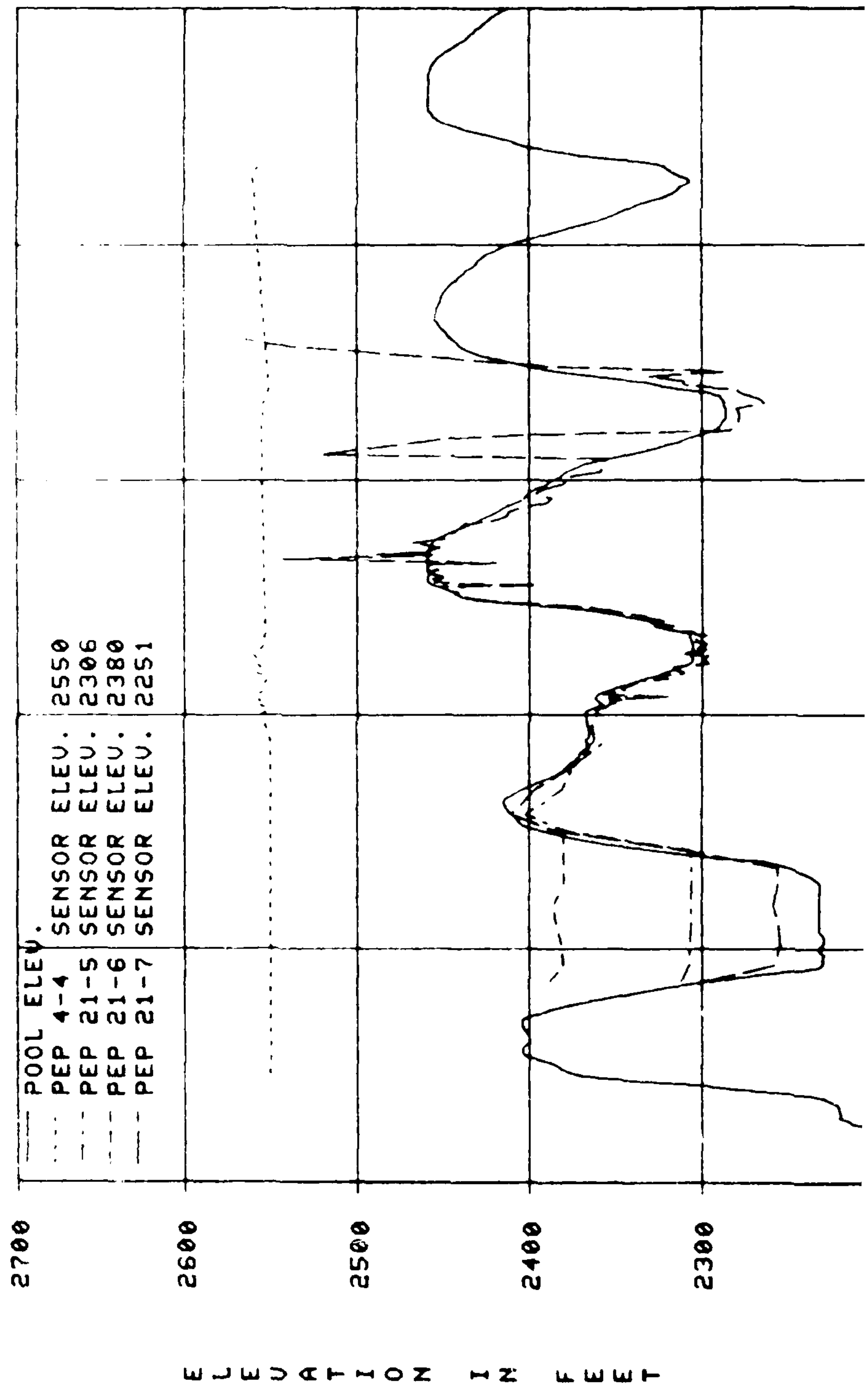
LIBBY LEFT BANK PIEZOMETERS (909 FAULT GROUP) 1/2

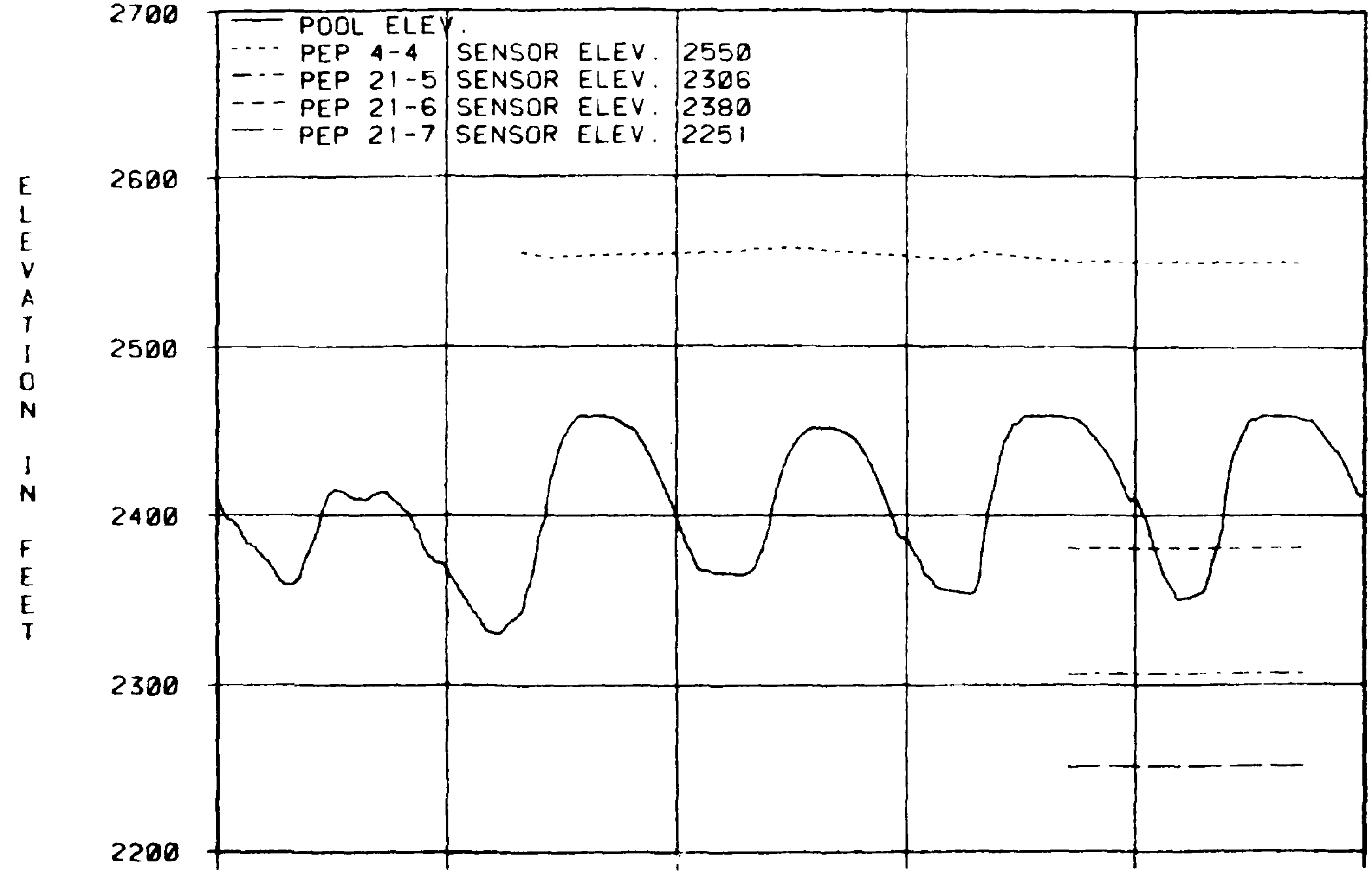


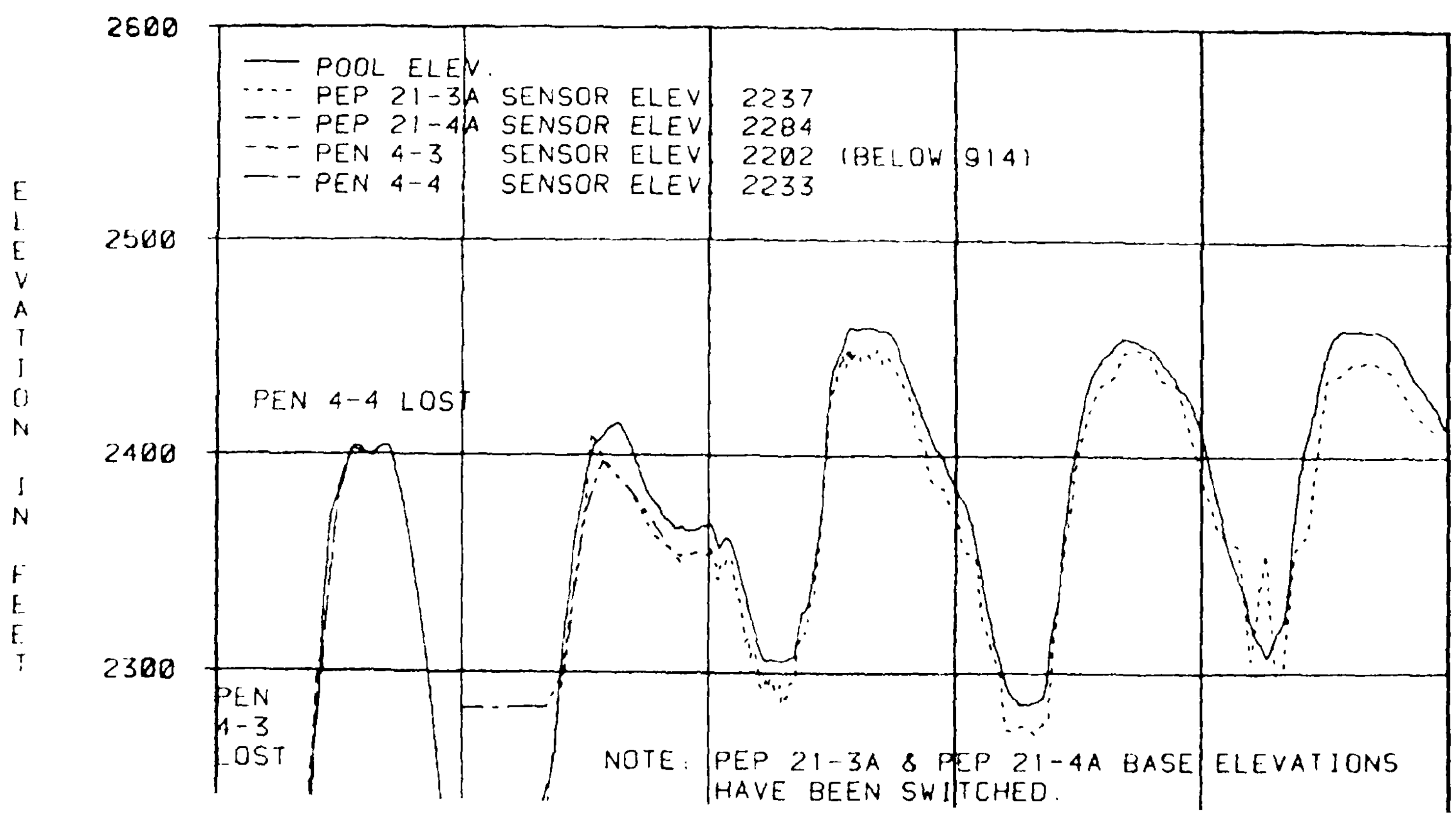
POOL ELEV.
PEP 12-1 SENSOR ELEV. 2414
PEP 12-2 SENSOR ELEV. 2451
PEP 12-3 SENSOR ELEV. 2495
PEP 22-6 SENSOR ELEV. 2413
2700
2600
2500
2400
2300
2200
ELEVATION IN FEET
1972
1973
1974
1975
1976
LIBBY LEFT BANK PIEZOMETERS (909 FAULT GROUP) 2/2

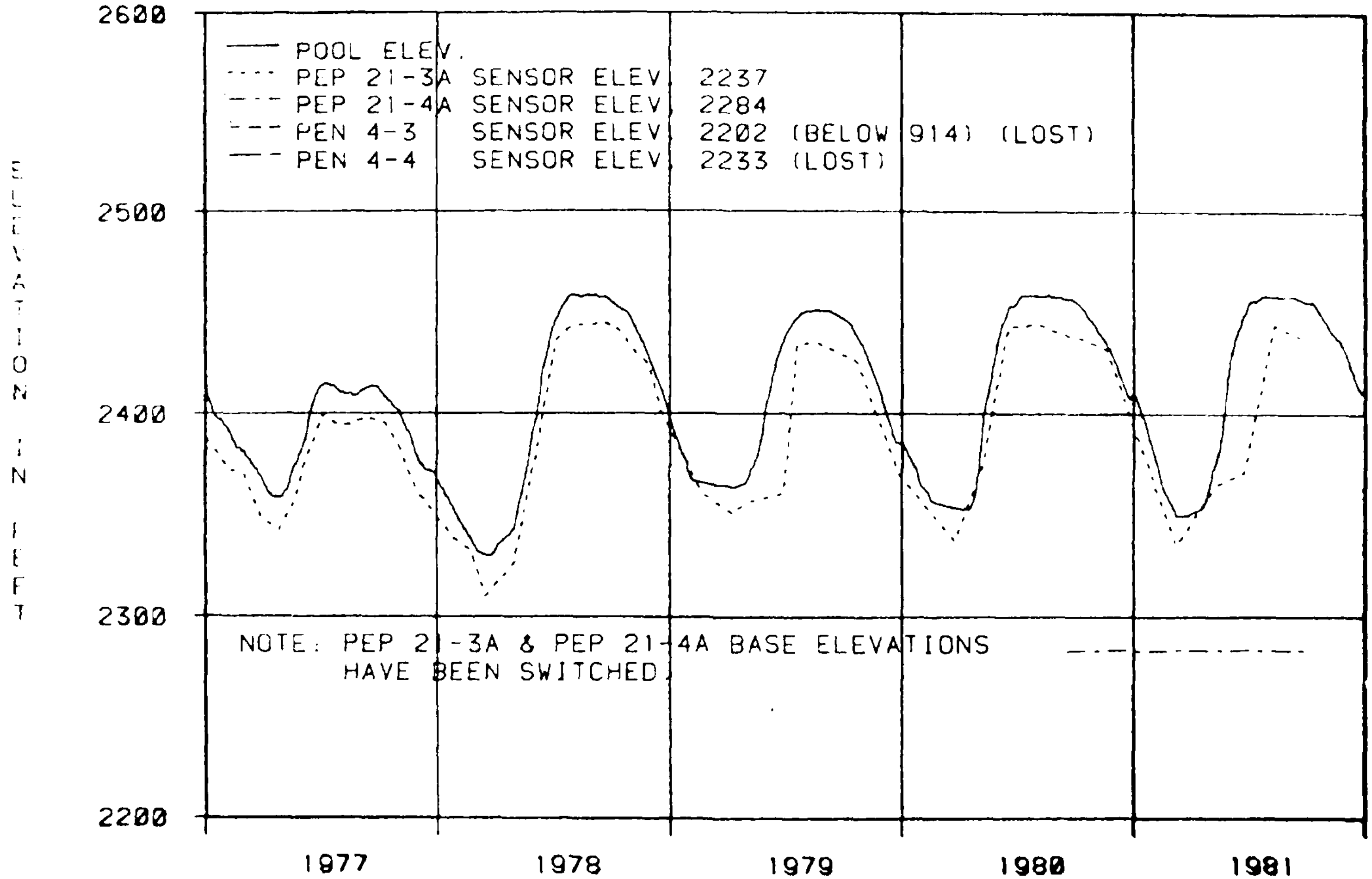

POOL ELEV
PEP 22-1 SENSOR ELEV. 2227
PEP 22-2 SENSOR ELEV. 2278
PEP 22-3 SENSOR ELEV. 2322
PEP 22-4 SENSOR ELEV. 2339
PEP 22-5 SENSOR ELEV. 2375
2600
2500
2400
2300
2200
ELEVATION IN FEET
1977
1978
1979
1980
1981
LIBBY LEFT BANK PIEZOMETERS (909 FAULT GROUP) 1/2


POOL ELEV
PEP 12-1 SENSOR ELEV. 2414
PEP 12-2 SENSOR ELEV. 2451
PEP 12-3 SENSOR ELEV. 2495
PEP 22-6 SENSOR ELEV. 2413
2700
2600
2500
2400
2300
2200
ELEVATION IN FEET
1977
1978
1979
1980
1981
LIBBY LEFT BANK PIEZOMETERS (909 FAULT GROUP) 2/2

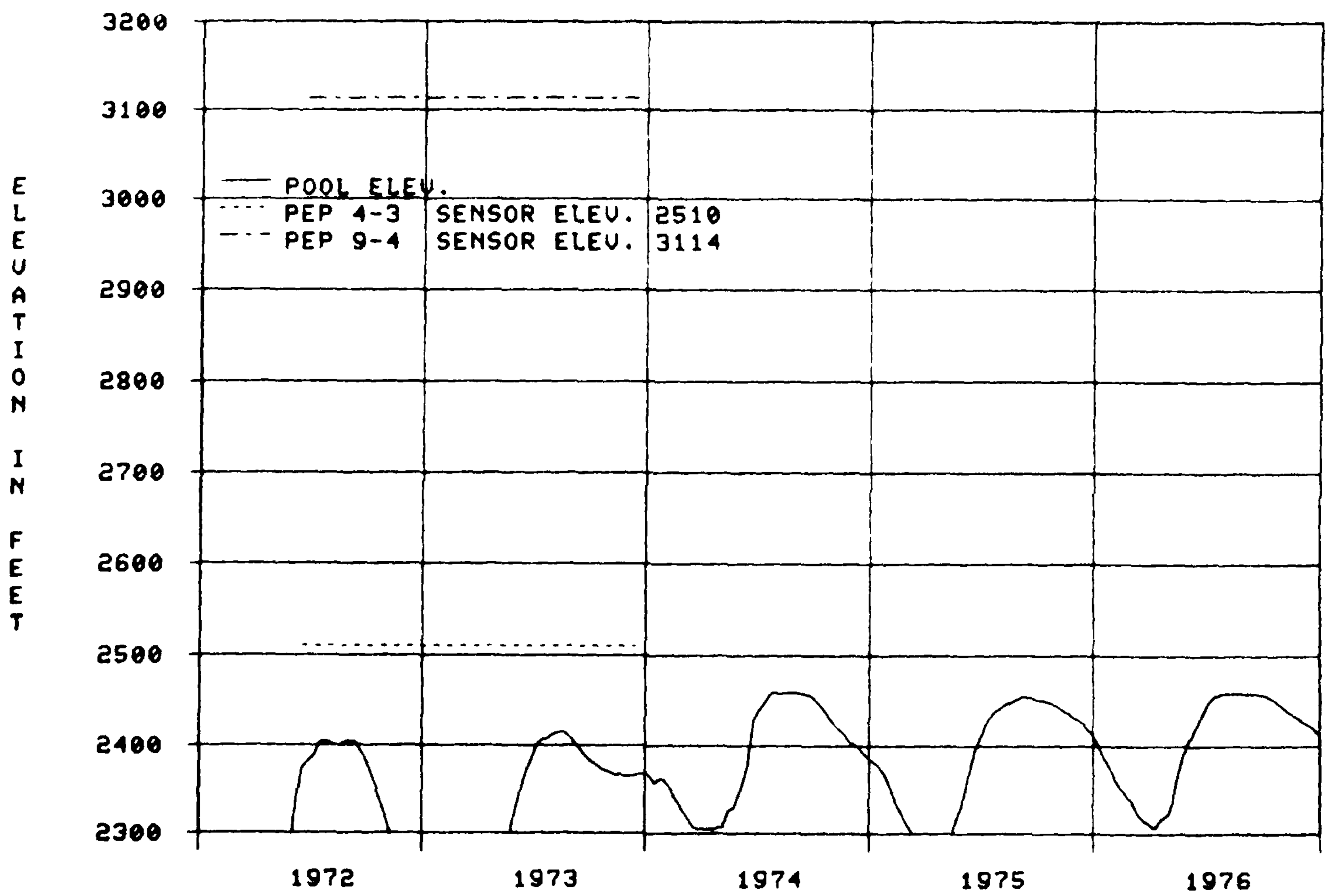

POOL ELEV.
PEP 4-4 SENSOR ELEV. 2550
PEP 21-5 SENSOR ELEV. 2306
PEP 21-6 SENSOR ELEV. 2380
PEP 21-7 SENSOR ELEV. 2251
2700
2600
2500
2400
2300
ELEVATION IN FEET


POOL ELEV.
PEP 4-4 SENSOR ELEV. 2550
PEP 21-5 SENSOR ELEV. 2306
PEP 21-6 SENSOR ELEV. 2380
PEP 21-7 SENSOR ELEV. 2251
2700
2600
2500
2400
2300
2200
ELEVATION IN FEET

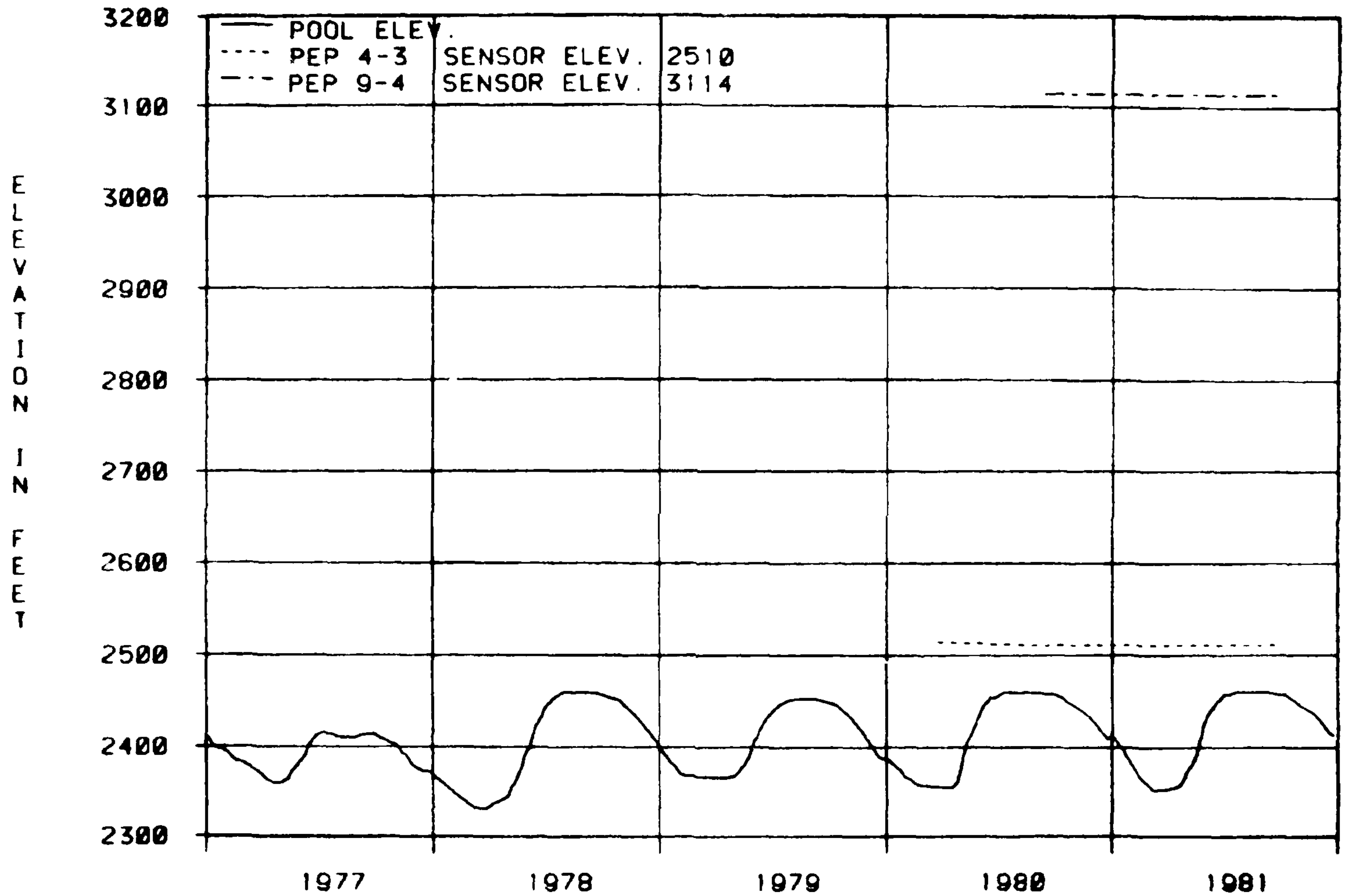

ELEVATION IN FEET
2600
2500
2400
2300
POOL ELEV.
PEP 21-3A SENSOR ELEV 2237
PEP 21-4A SENSOR ELEV 2284
PEN 4-3 SENSOR ELEV 2202 (BELOW 914)
PEN 4-4 SENSOR ELEV 2233
PEN 4-4 LOST
PEN 4-3 LOST
NOTE: PEP 21-3A & PEP 21-4A BASE ELEVATIONS HAVE BEEN SWITCHED.



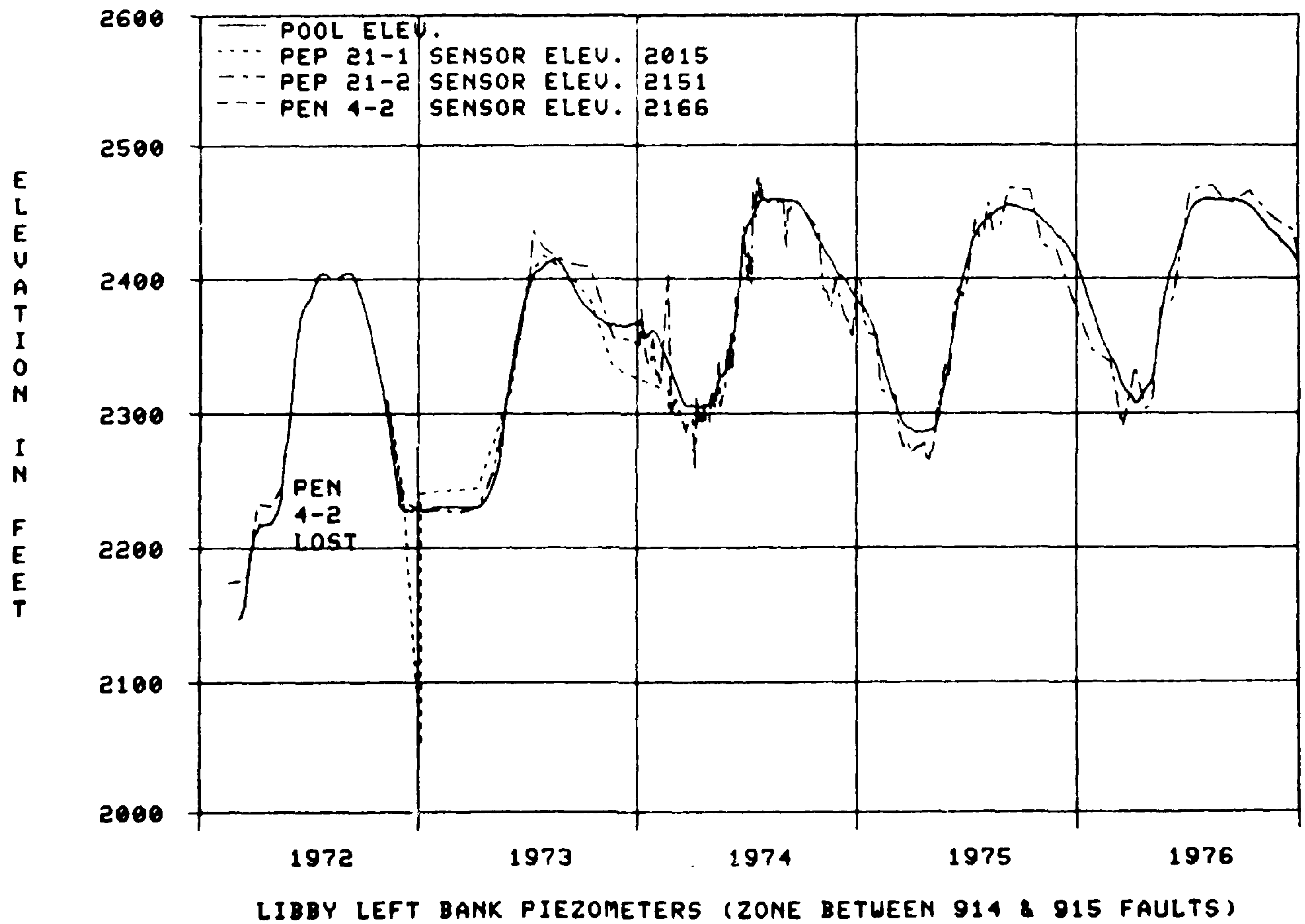
LIBBY LEFT BANK PIEZOMETERS (914 FAULT GROUP) 1/2



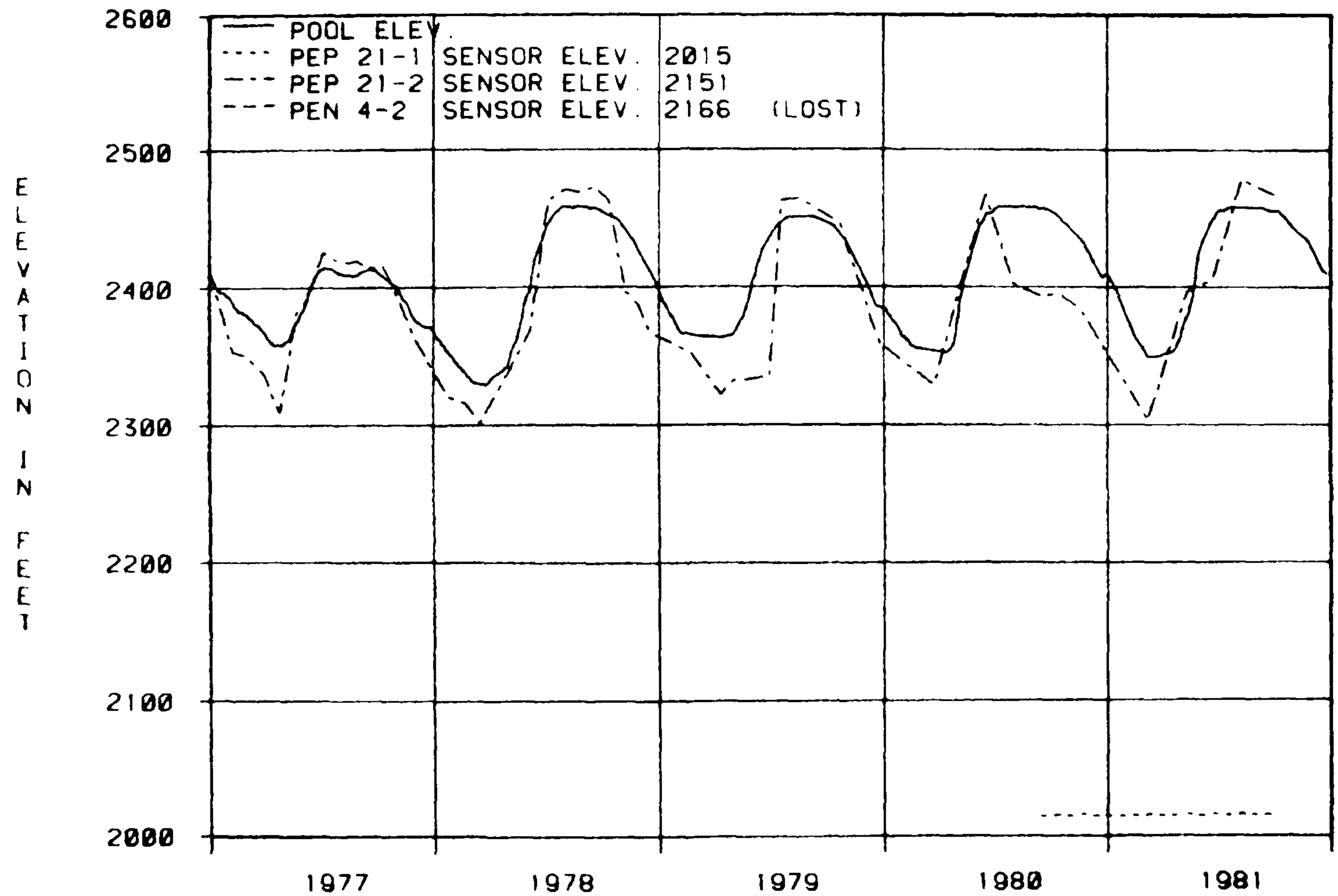
LIBBY LEFT BANK PIEZOMETERS (914 FAULT GROUP) 2/2



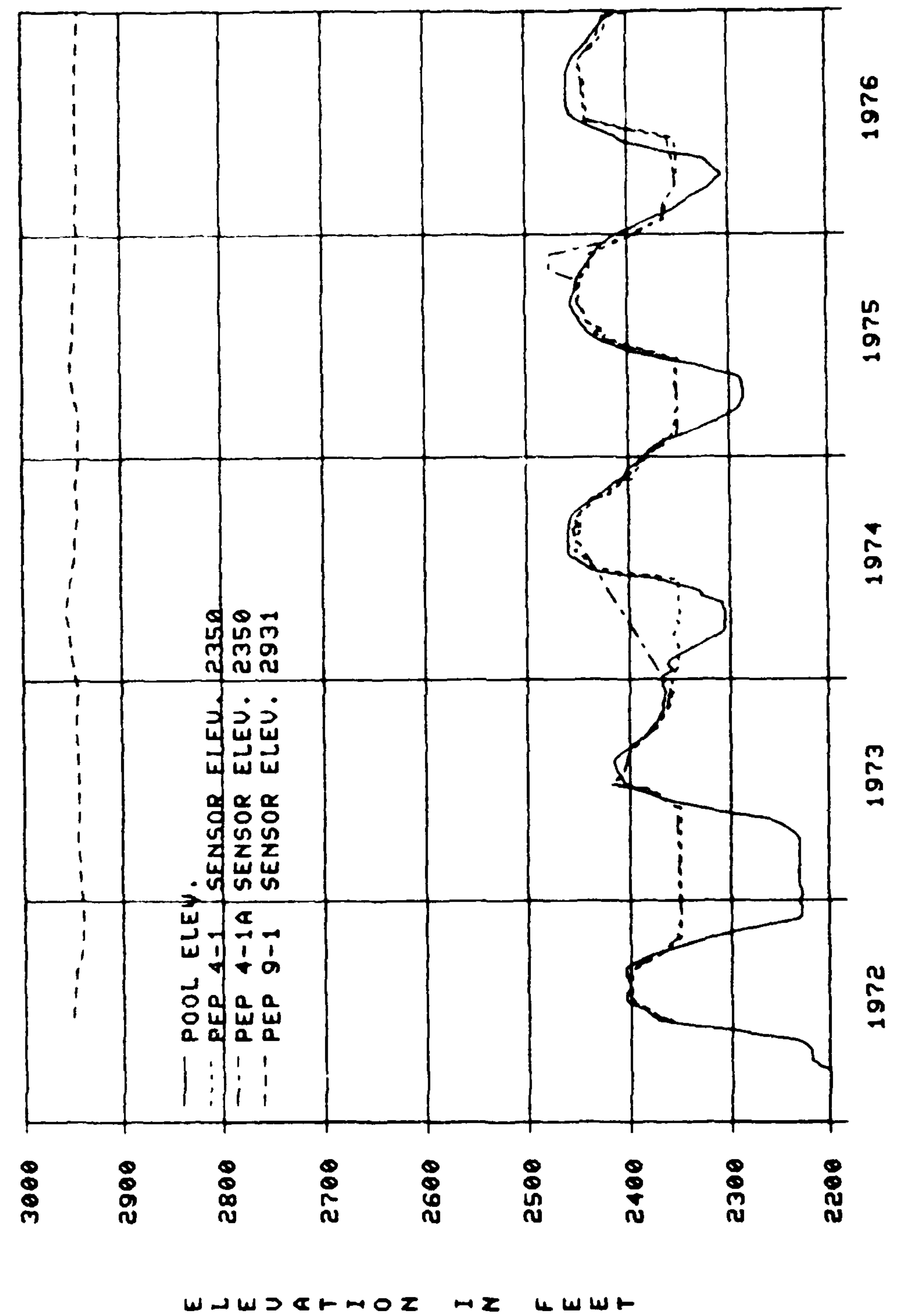
LIBBY LEFT BANK PIEZOMETERS (914 FAULT GROUP) 2/2



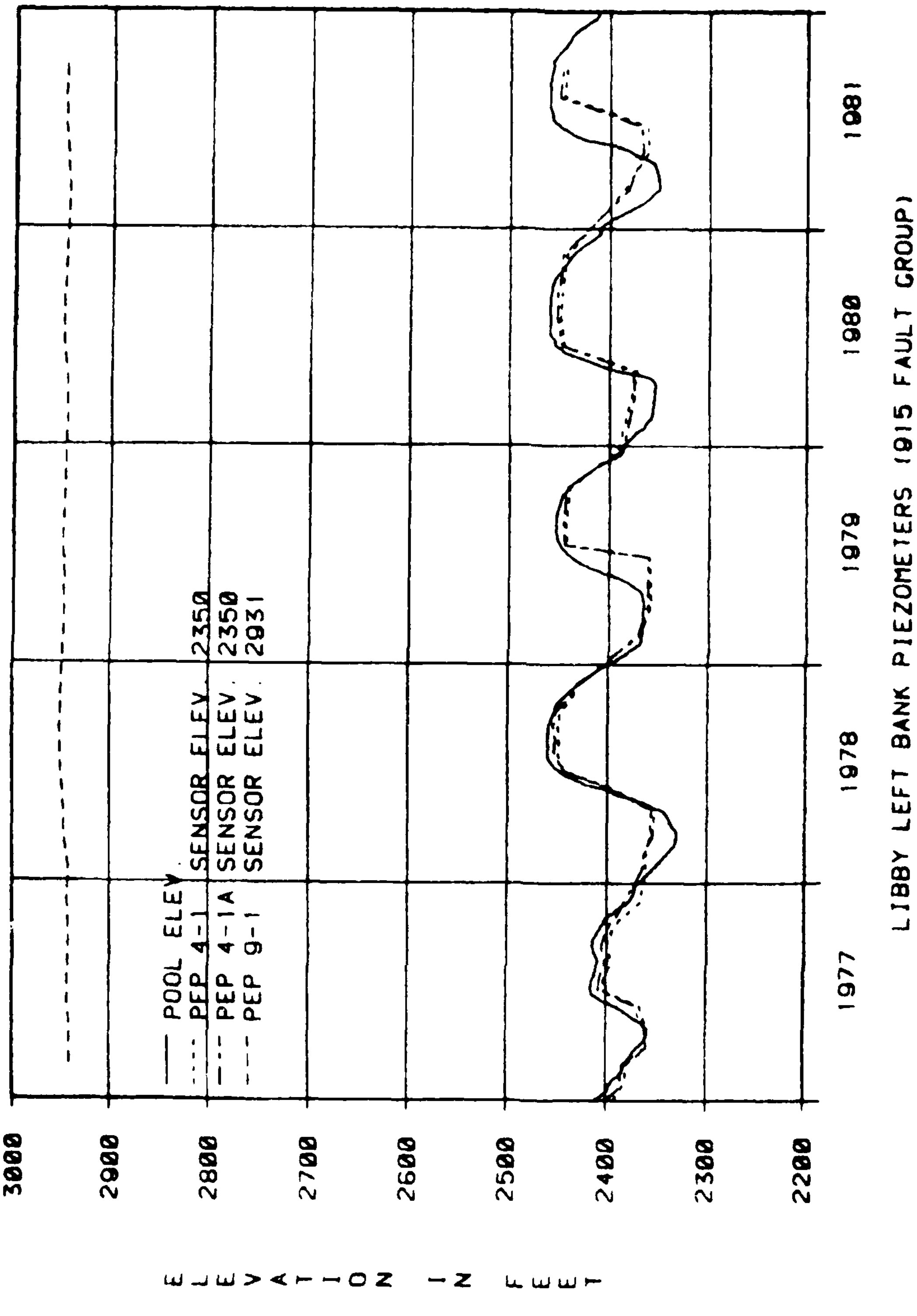
POOL ELEV.
PEP 21-1 SENSOR ELEV. 2015
PEP 21-2 SENSOR ELEV. 2151
PEN 4-2 SENSOR ELEV. 2166
PEN 4-2 LOST
2600
2500
2400
2300
2200
2100
2000
ELEVATION IN FEET
1972
1973
1974
1975
1976
LIBBY LEFT BANK PIEZOMETERS (ZONE BETWEEN 914 & 915 FAULTS)



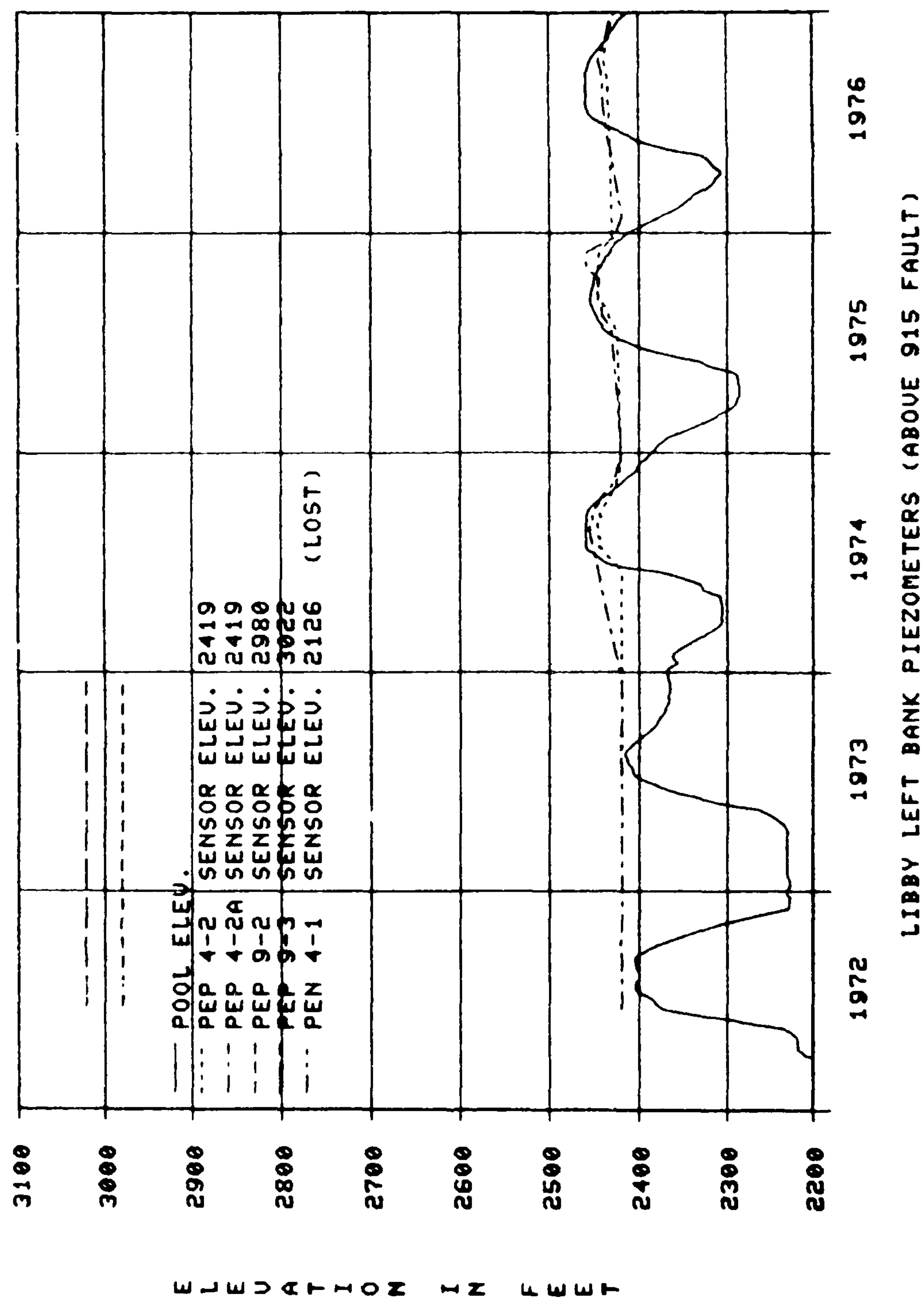
LIBBY LEFT BANK PIEZOMETERS (ZONE BETWEEN 914 & 915 FAULTS)

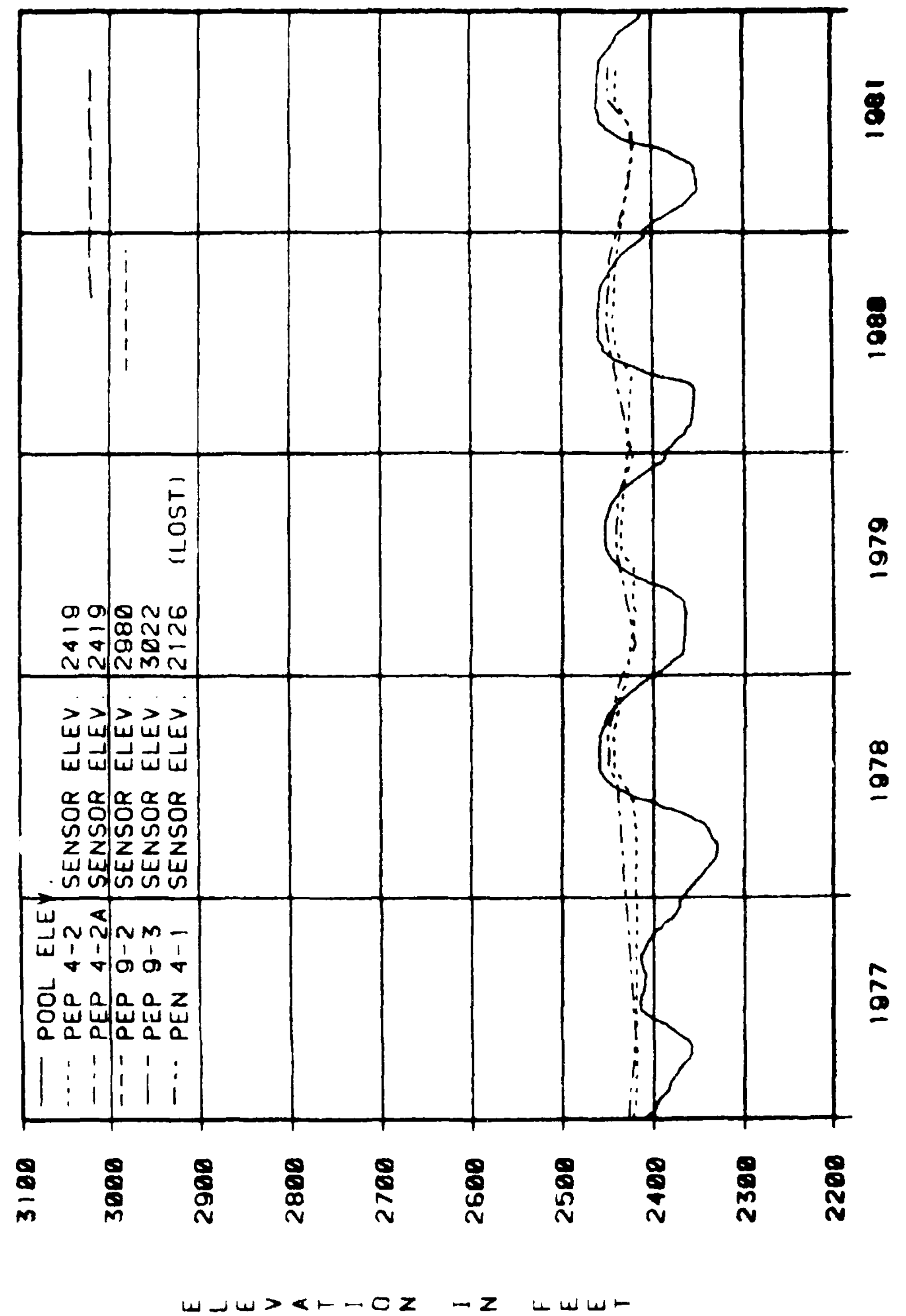


LIBBY LEFT BANK PIEZOMETERS (915 FAULT GROUP)

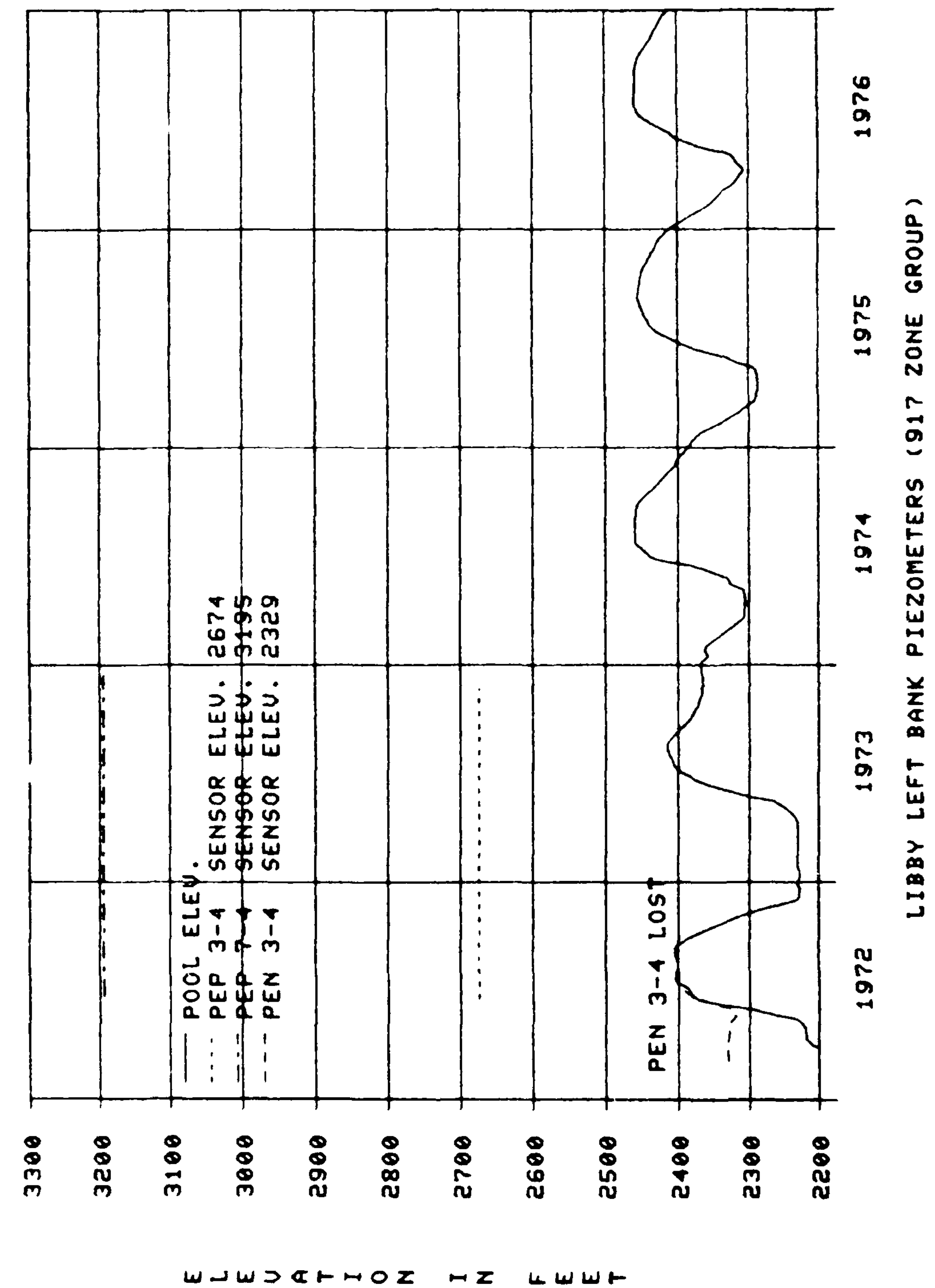


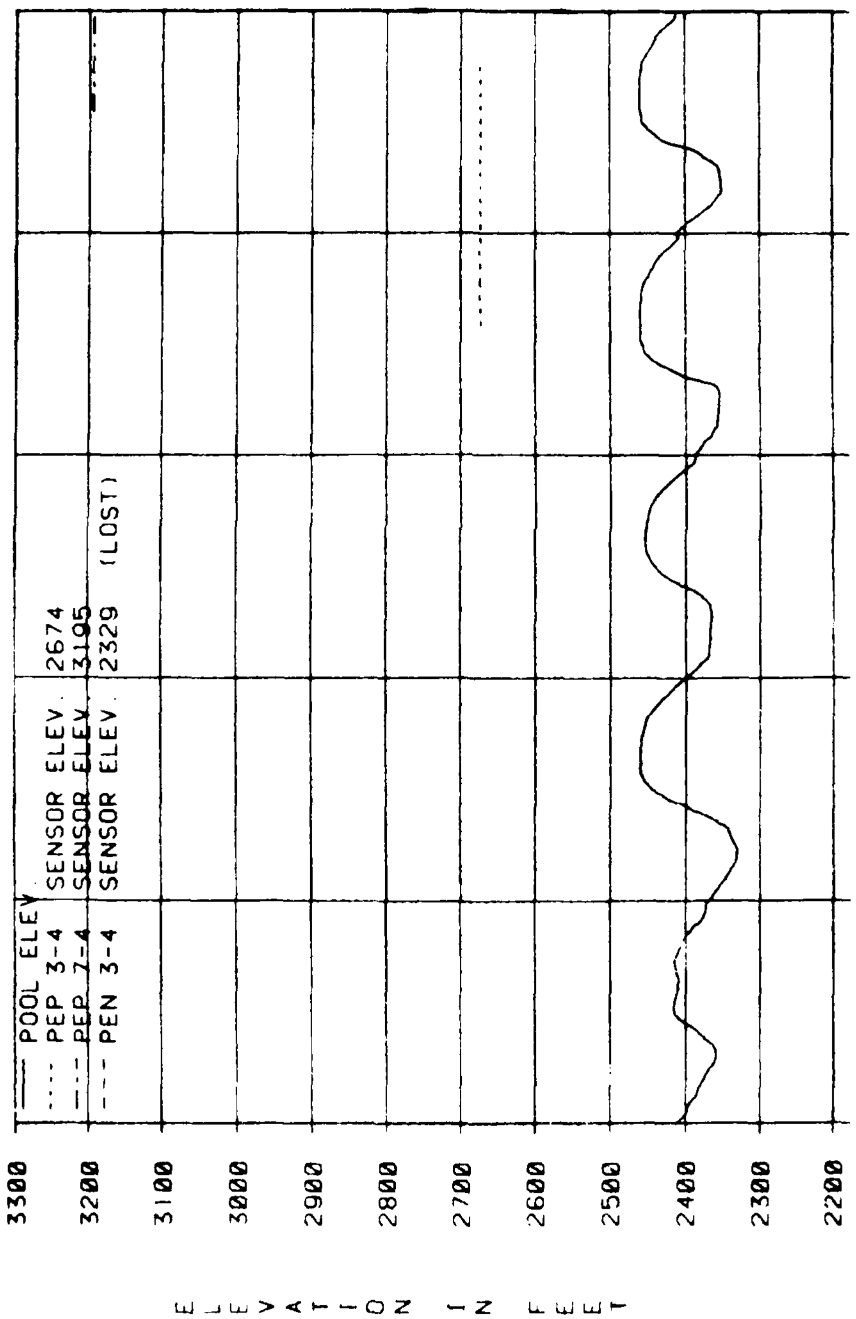
POOL ELEV.
PEP 4-1 SENSOR ELEV. 2350
PEP 4-1A SENSOR ELEV. 2350
PEP 9-1 SENSOR ELEV. 2931
3000
2900
2800
2700
2600
2500
2400
2300
2200
ELEVATION IN FEET
1977
1978
1979
1980
1981
LIBBY LEFT BANK PIEZOMETERS (915 FAULT GROUP)


LIBBY LEFT BANK PIEZOMETERS (ABOVE 915 FAULT)
ELEVATION IN FEET
3100
3000
2900
2800
2700
2600
2500
2400
2300
2200
1972
1973
1974
1975
1976
POOL ELEV.
PEP 4-2 SENSOR ELEV. 2419
PEP 4-2A SENSOR ELEV. 2419
PEP 9-2 SENSOR ELEV. 2980
PEP 9-3 SENSOR ELEV. 3022
PEN 4-1 SENSOR ELEV. 2126 (LOST)



LIBBY LEFT BANK PIEZOMETERS (ABOVE 915 FAULT)


LIBBY LEFT BANK PIEZOMETERS (917 ZONE GROUP)
POOL ELEV.
PEP 3-4 SENSOR ELEV. 2674
PEP 7-4 SENSOR ELEV. 3195
PEN 3-4 SENSOR ELEV. 2329
PEN 3-4 LOST
1972
1973
1974
1975
1976
3300
3200
3100
3000
2900
2800
2700
2600
2500
2400
2300
2200
ELEVATION IN FEET



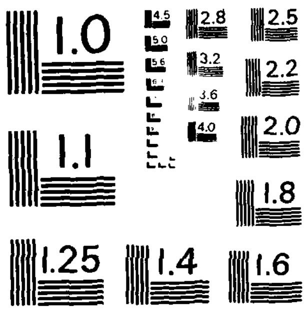
LIBBY LEFT BANK PIEZOMETERS (917 ZONE GROUP)

AD-A142 021 LIBBY DAM AND LAKE KOOCANUSA PROJECT MONTANA LEFT BANK SLOPE(U) CORPS OF ENGINEERS SEATTLE WA SEATTLE DISTRICT APR 84

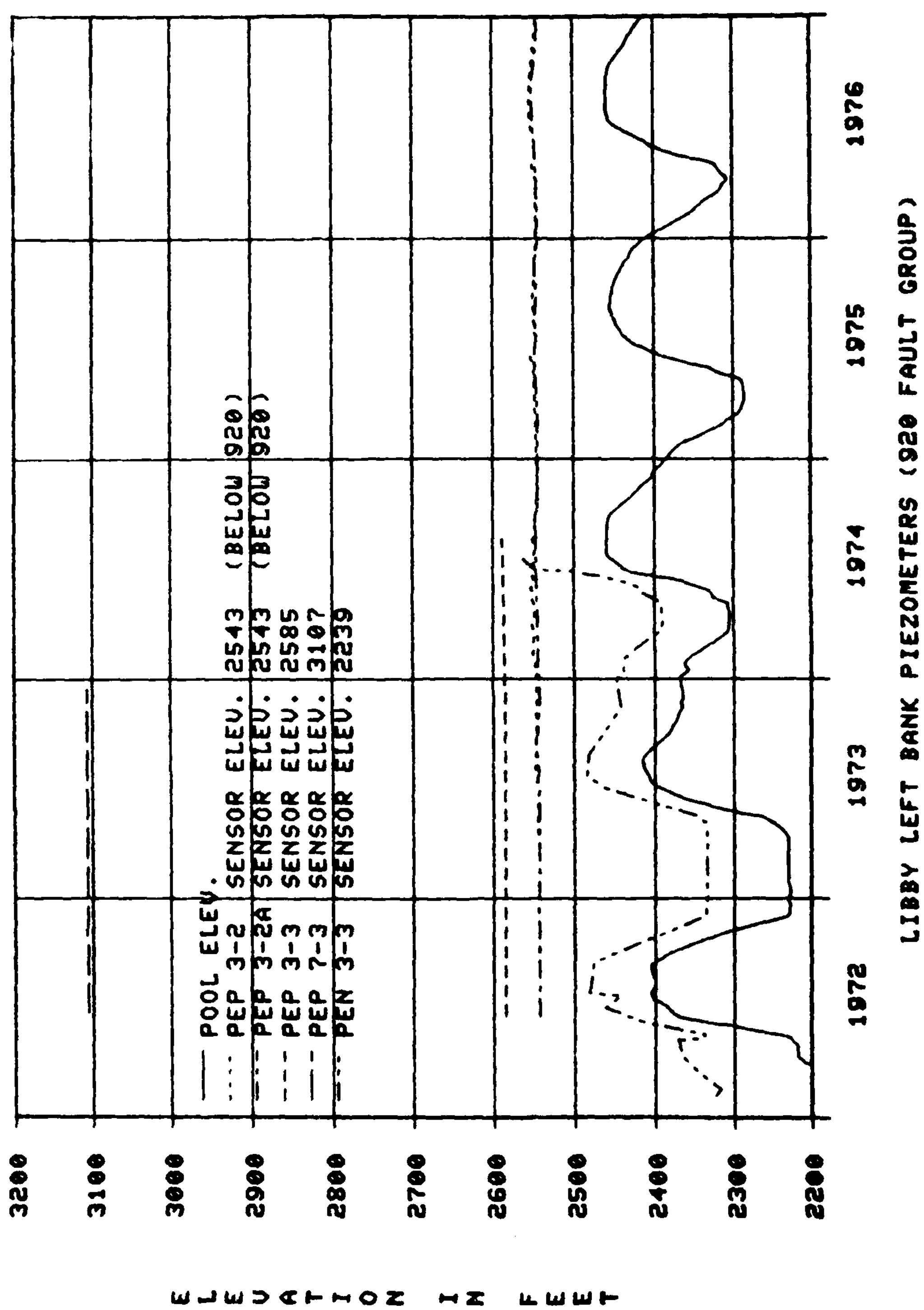
6/6

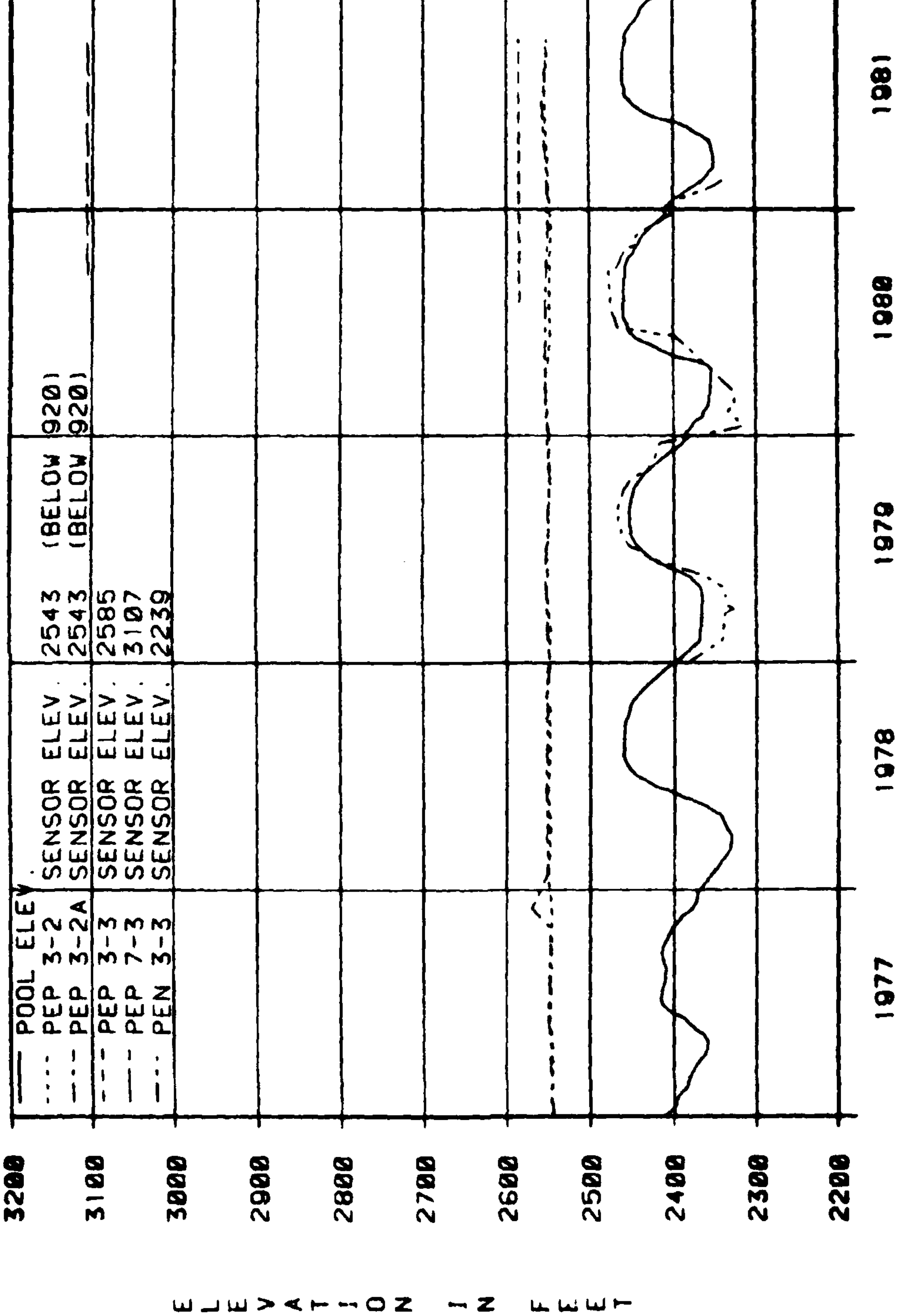
UNCLASSIFIED F/G 13/2 NL

END
DATE FILMED
7 84
DTIC

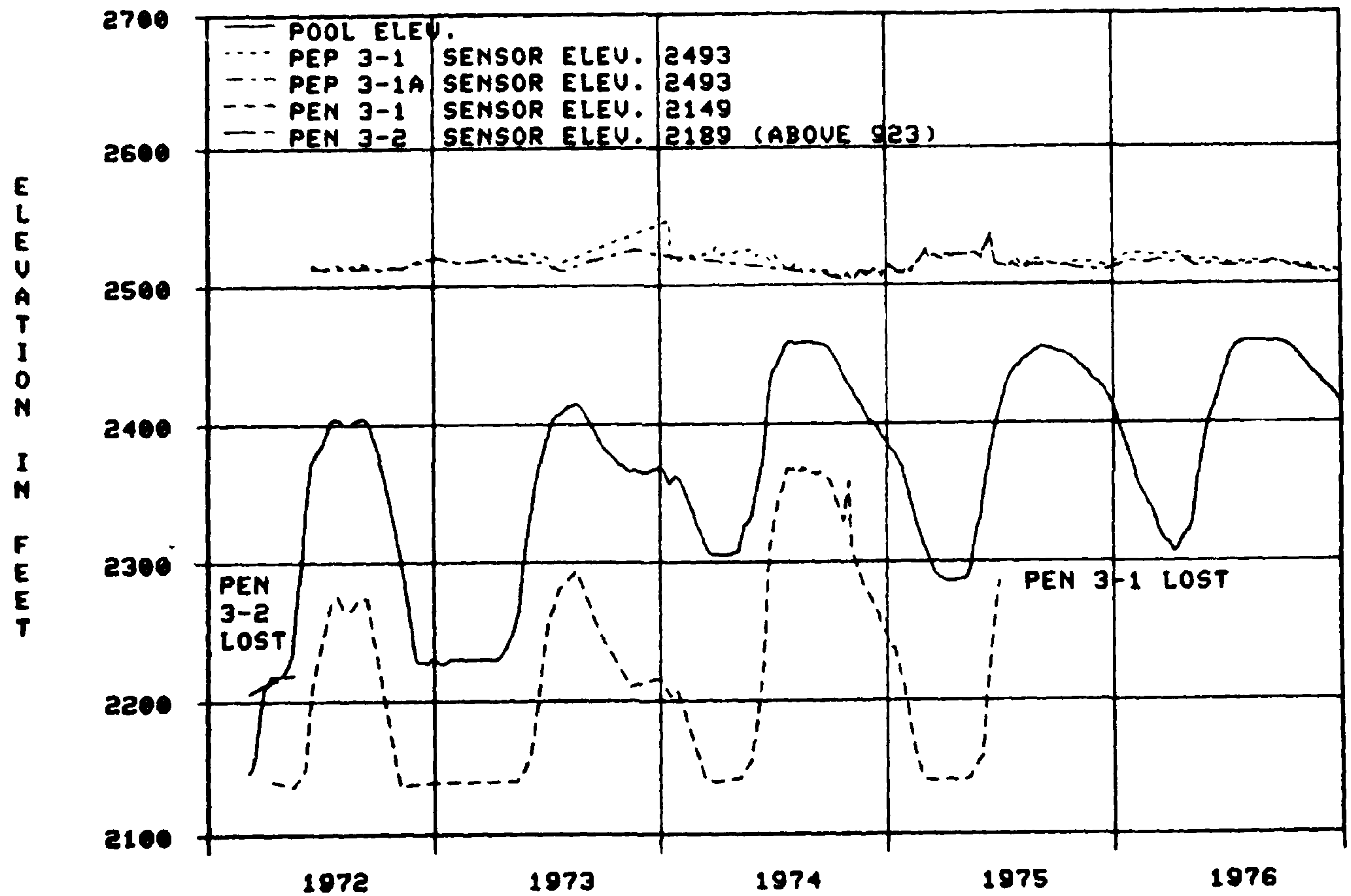


MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

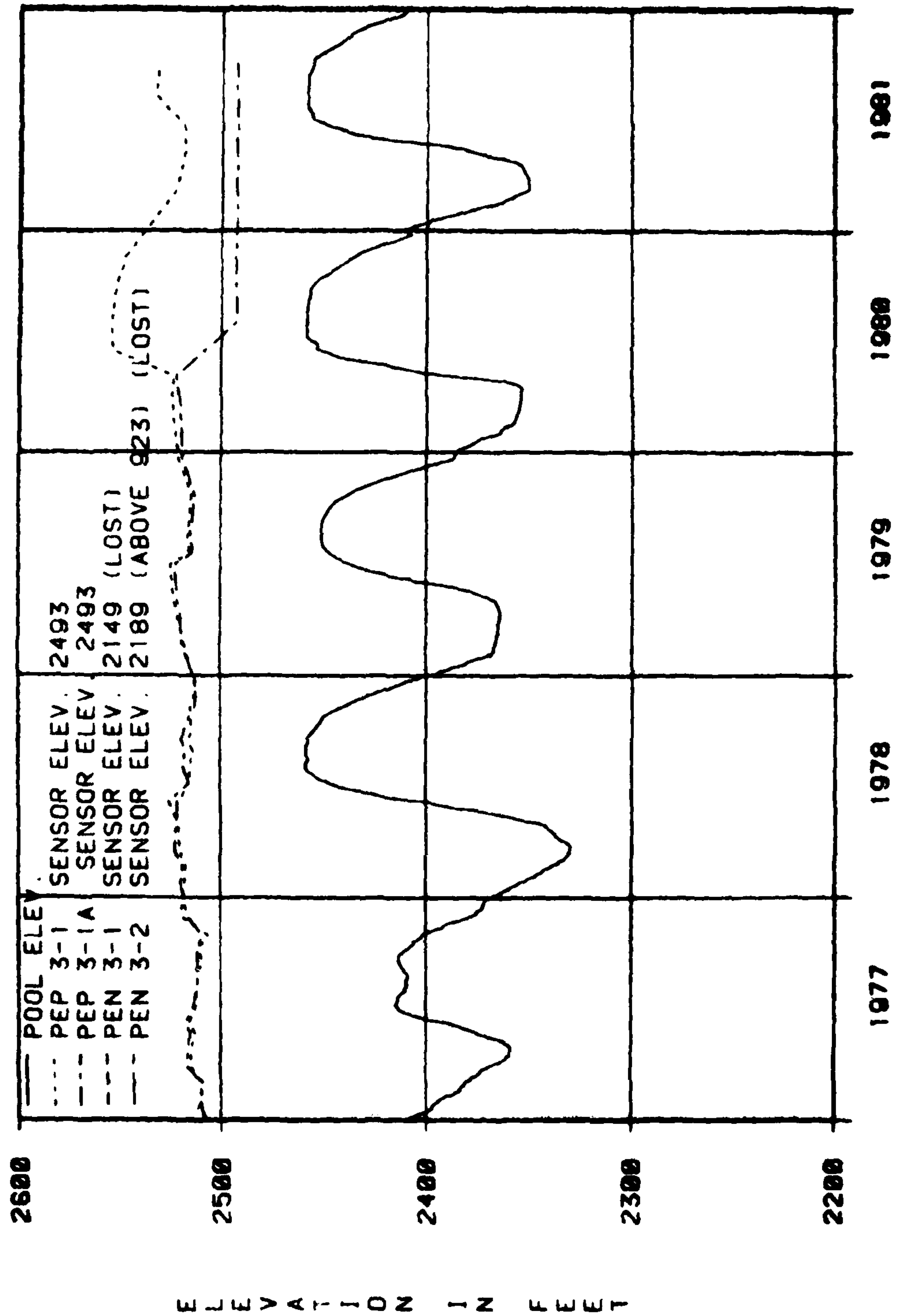

LIBBY LEFT BANK PIEZOMETERS (920 FAULT GROUP)
POOL ELEV.
PEP 3-2 SENSOR ELEV. 2543 (BELOW 920)
PEP 3-2A SENSOR ELEV. 2543 (BELOW 920)
PEP 3-3 SENSOR ELEV. 2585
PEP 7-3 SENSOR ELEV. 3107
PEN 3-3 SENSOR ELEV. 2239
1972
1973
1974
1975
1976
3200
3100
3000
2900
2800
2700
2600
2500
2400
2300
2200
ELEVATION IN FEET



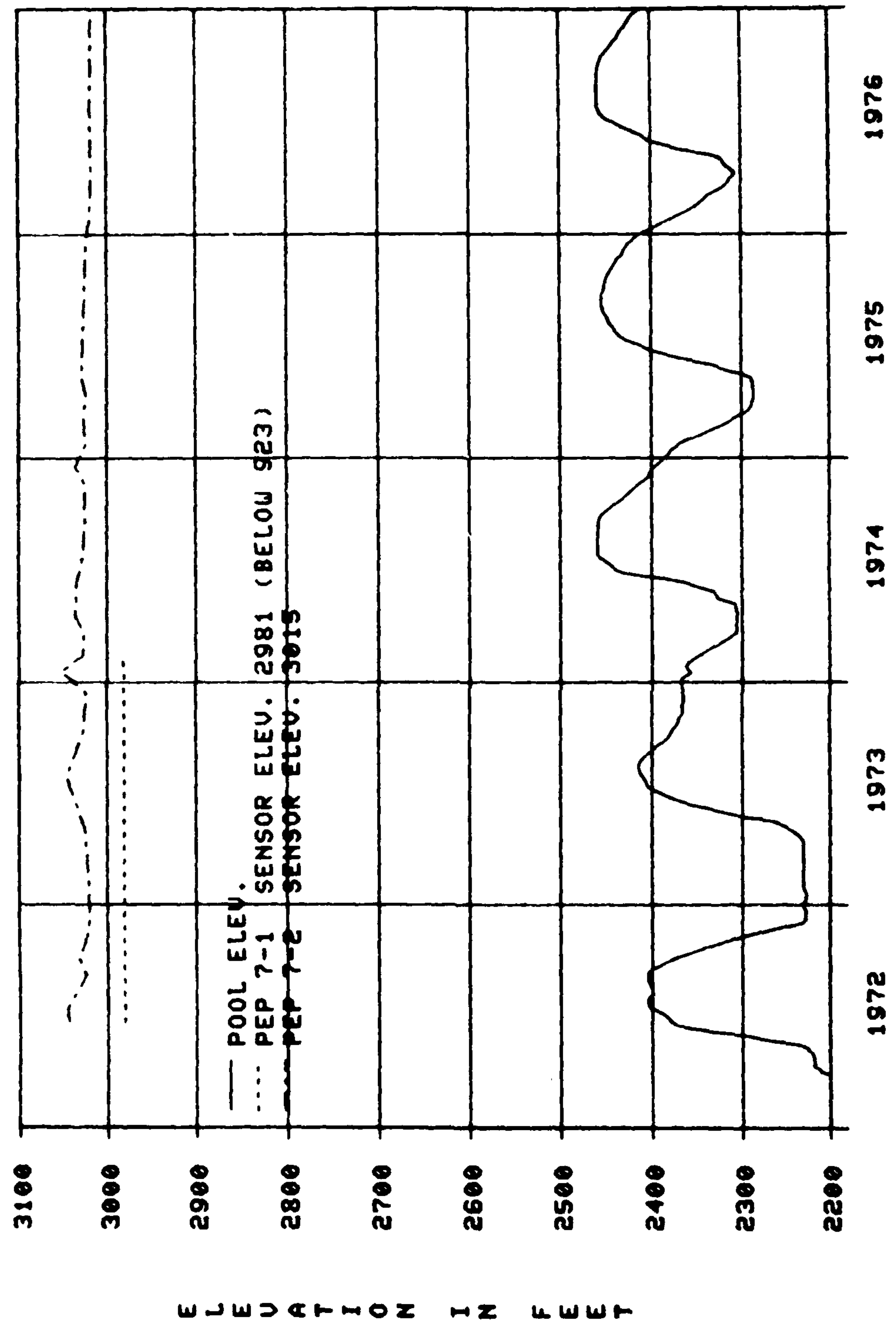
LIBBY LEFT BANK PIEZOMETERS (1920 FAULT GROUP)



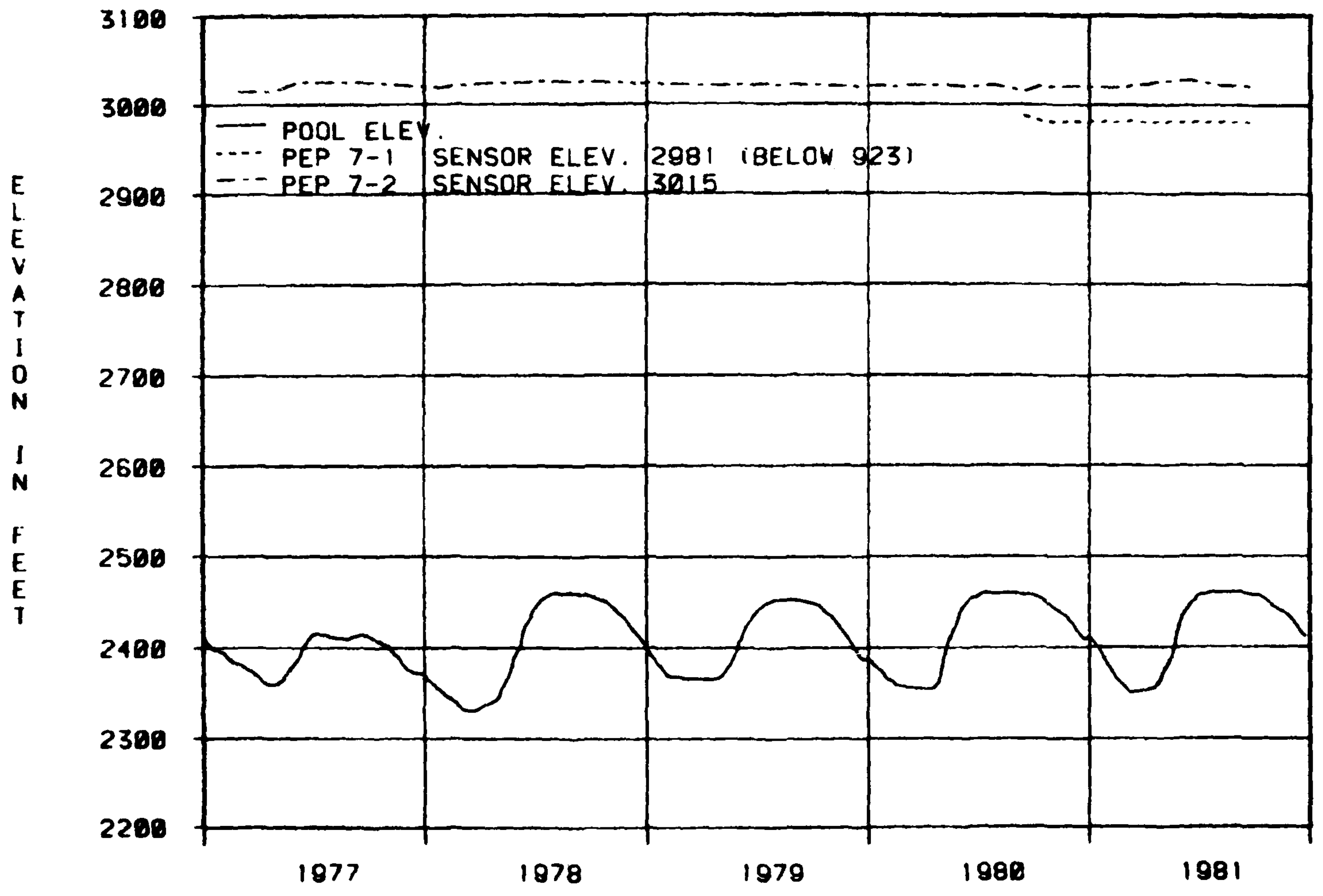
LIBBY LEFT BANK PIEZOMETERS (923 FAULT GROUP) 1/2



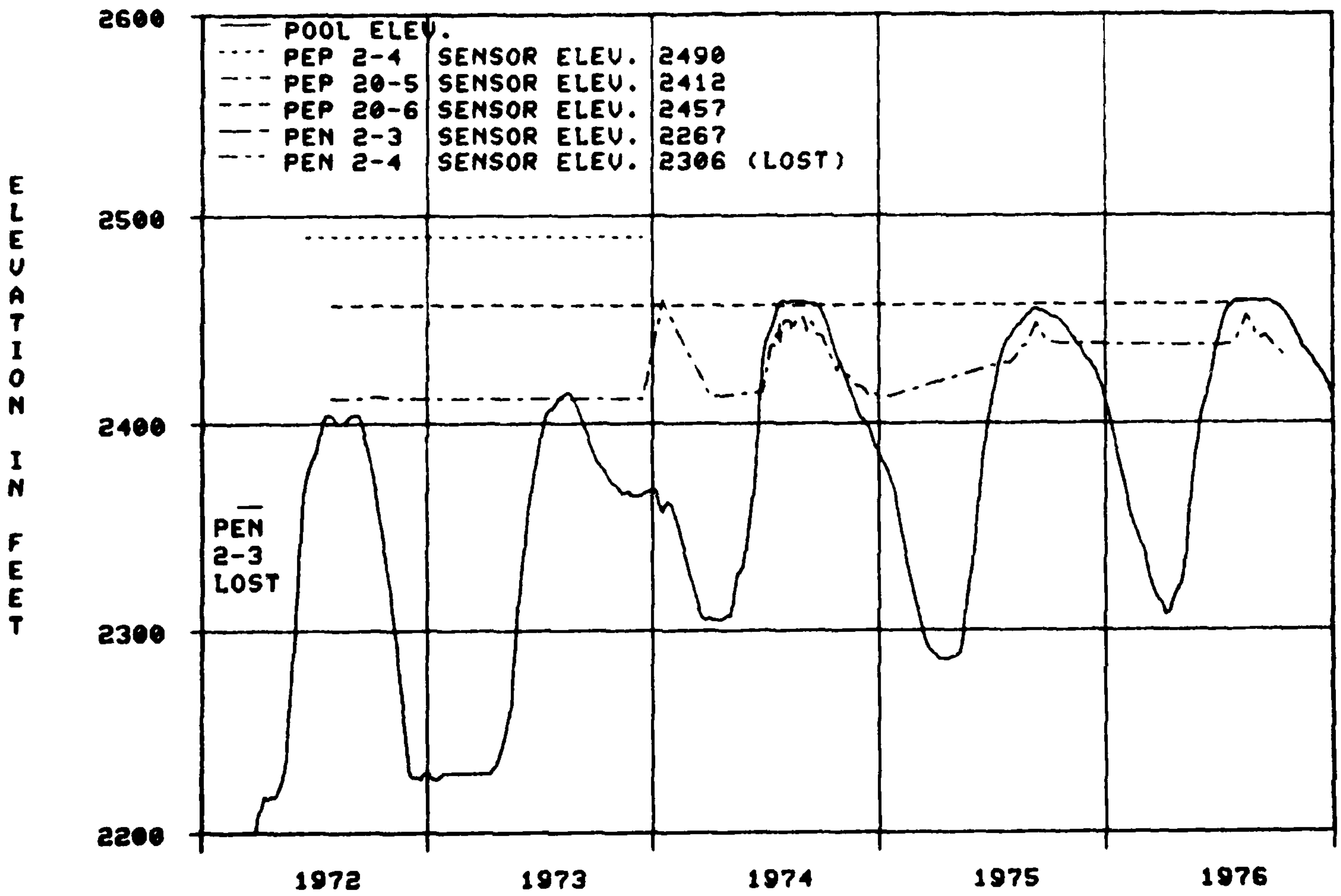
LIBBY LEFT BANK PIEZOMETERS (923 FAULT GROUP) 1/2



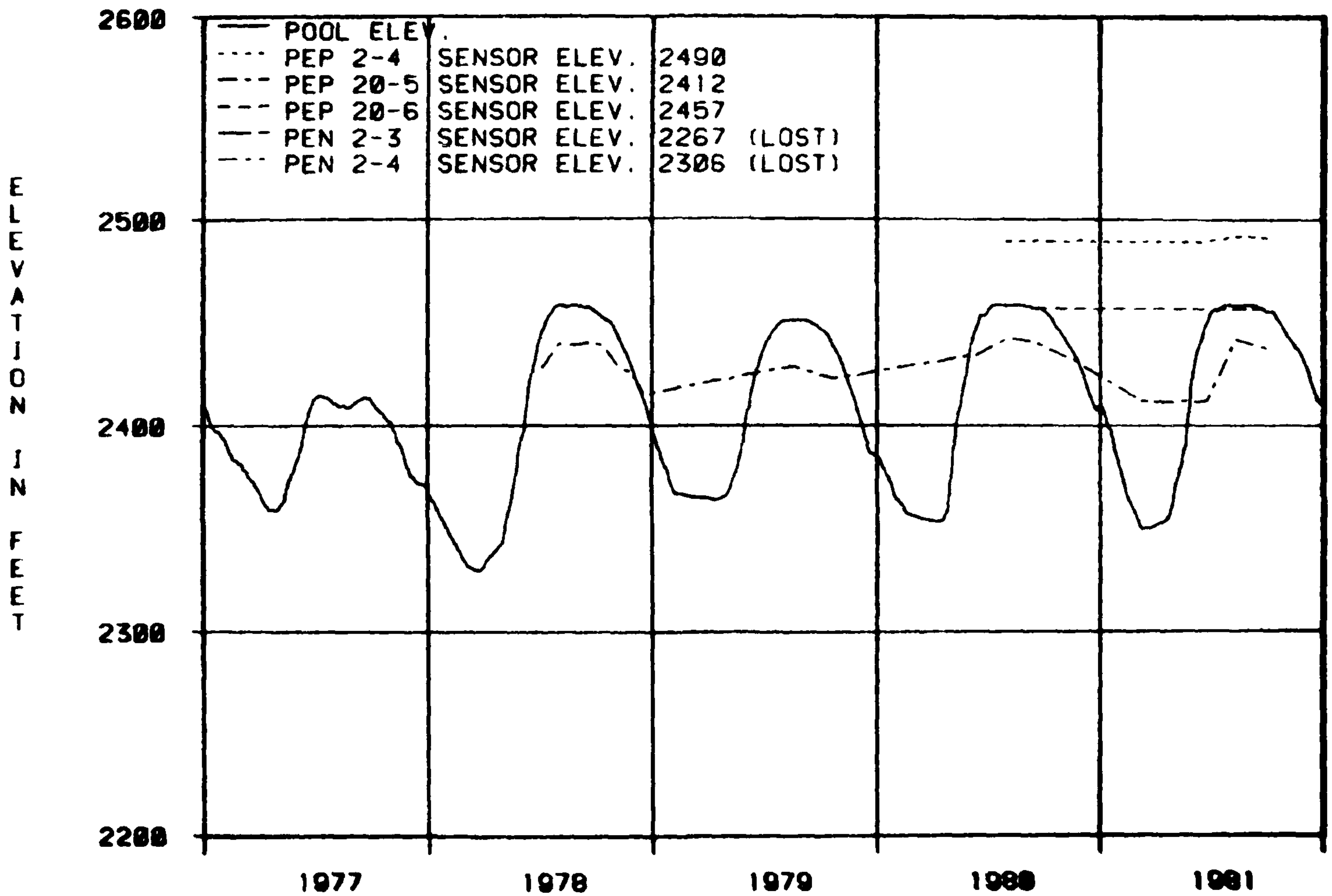
LIBBY LEFT BANK PIEZOMETERS (923 FAULT GROUP) 2/2



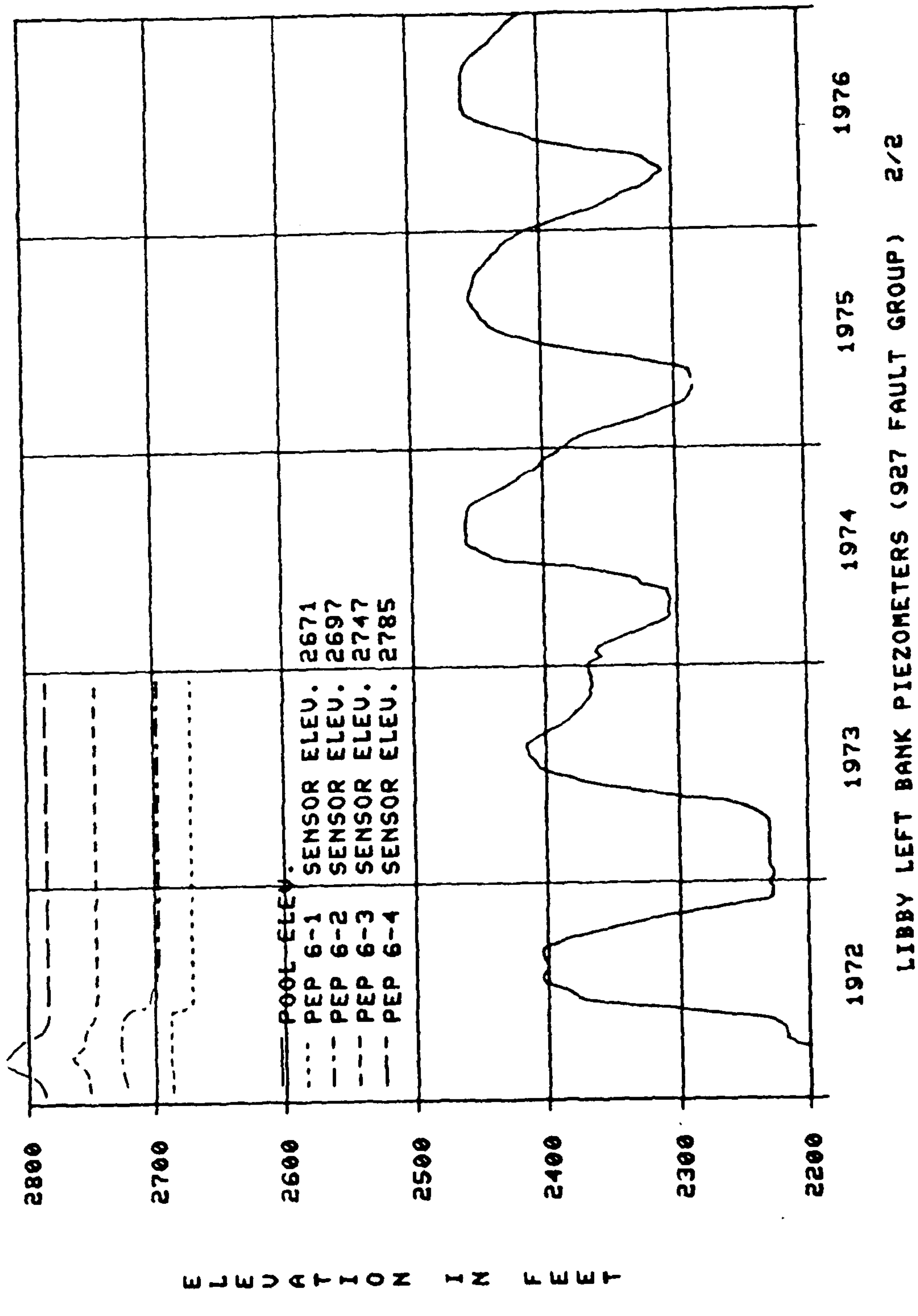
LIBBY LEFT BANK PIEZOMETERS (923 FAULT GROUP) 2/2



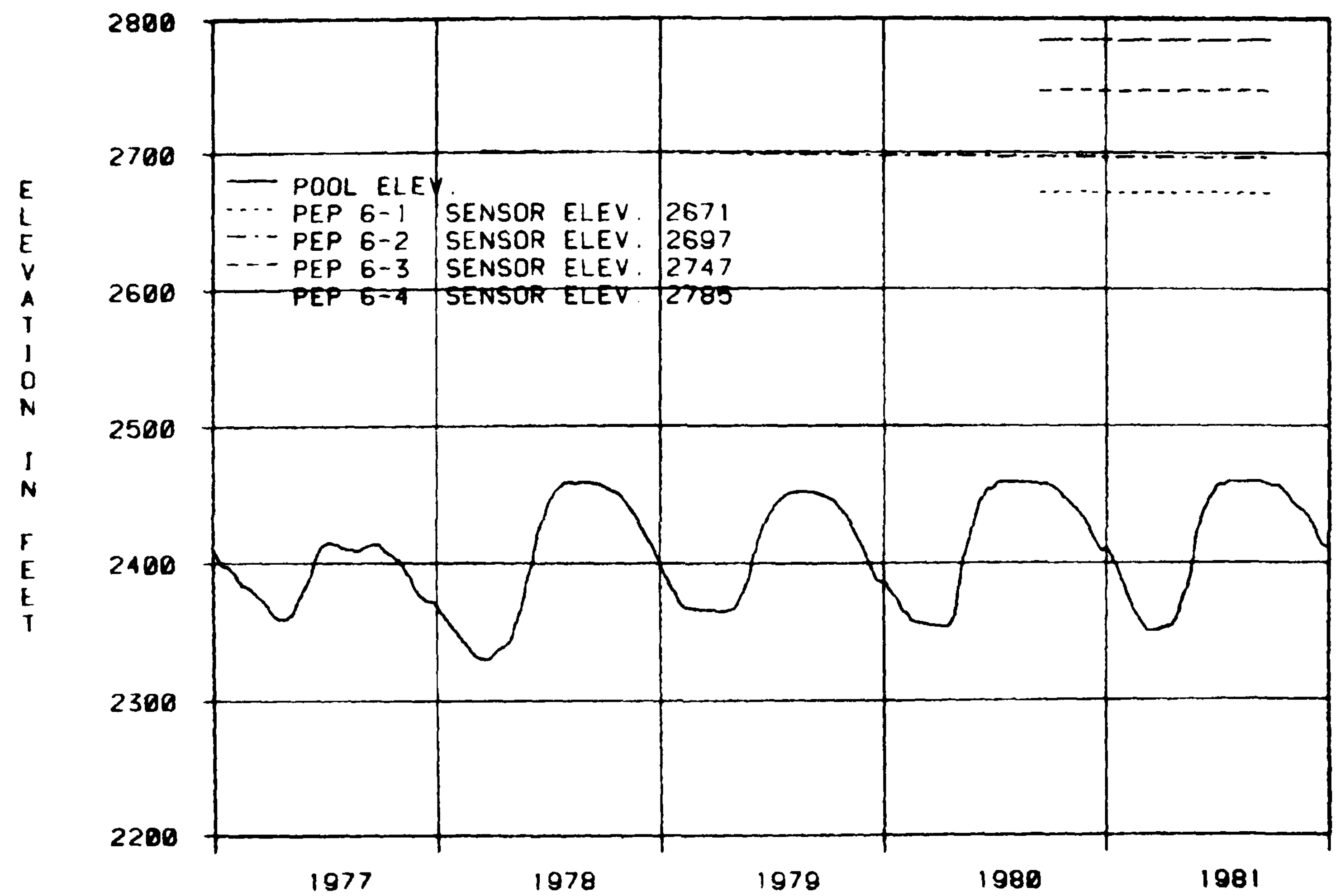
LIBBY LEFT BANK PIEZOMETERS (927 FAULT GROUP) 1/2



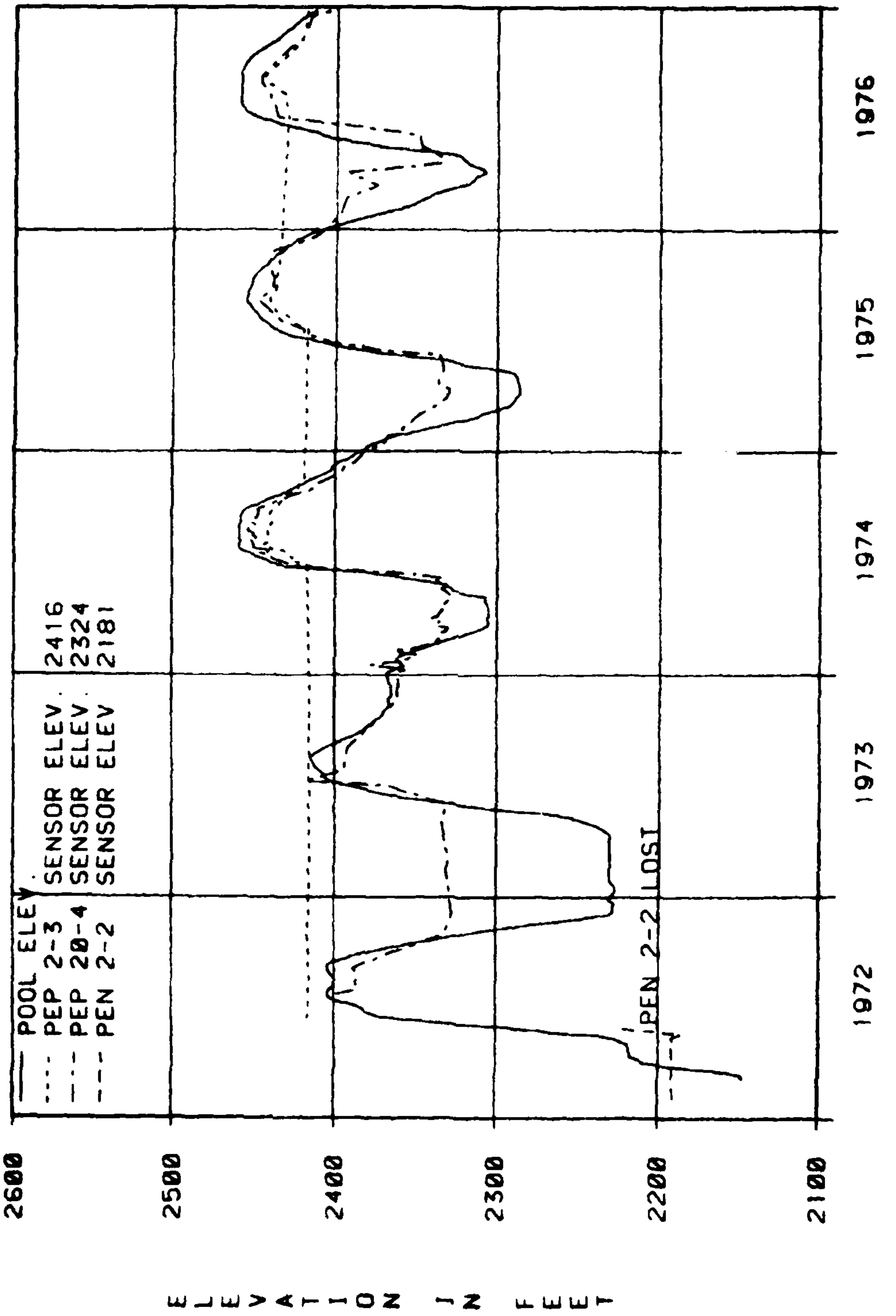
LIBBY LEFT BANK PIEZOMETERS (927 FAULT GROUP) 1/2



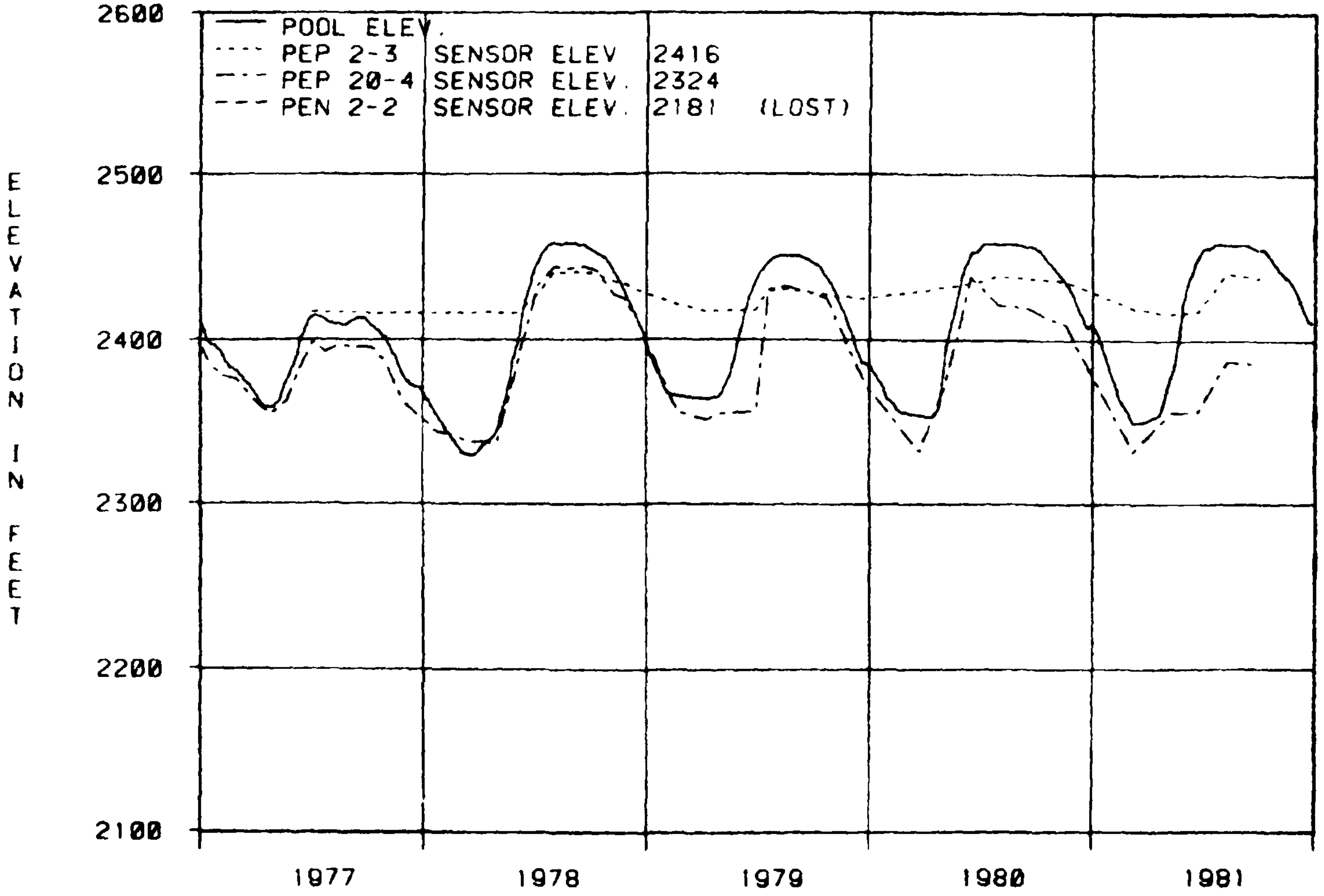
POOL ELEV.
PEP 6-1 SENSOR ELEV. 2671
PEP 6-2 SENSOR ELEV. 2697
PEP 6-3 SENSOR ELEV. 2747
PEP 6-4 SENSOR ELEV. 2785
2800
2700
2600
2500
2400
2300
2200
ELEVATION IN FEET
1972
1973
1974
1975
1976
LIBBY LEFT BANK PIEZOMETERS (927 FAULT GROUP) 2/2



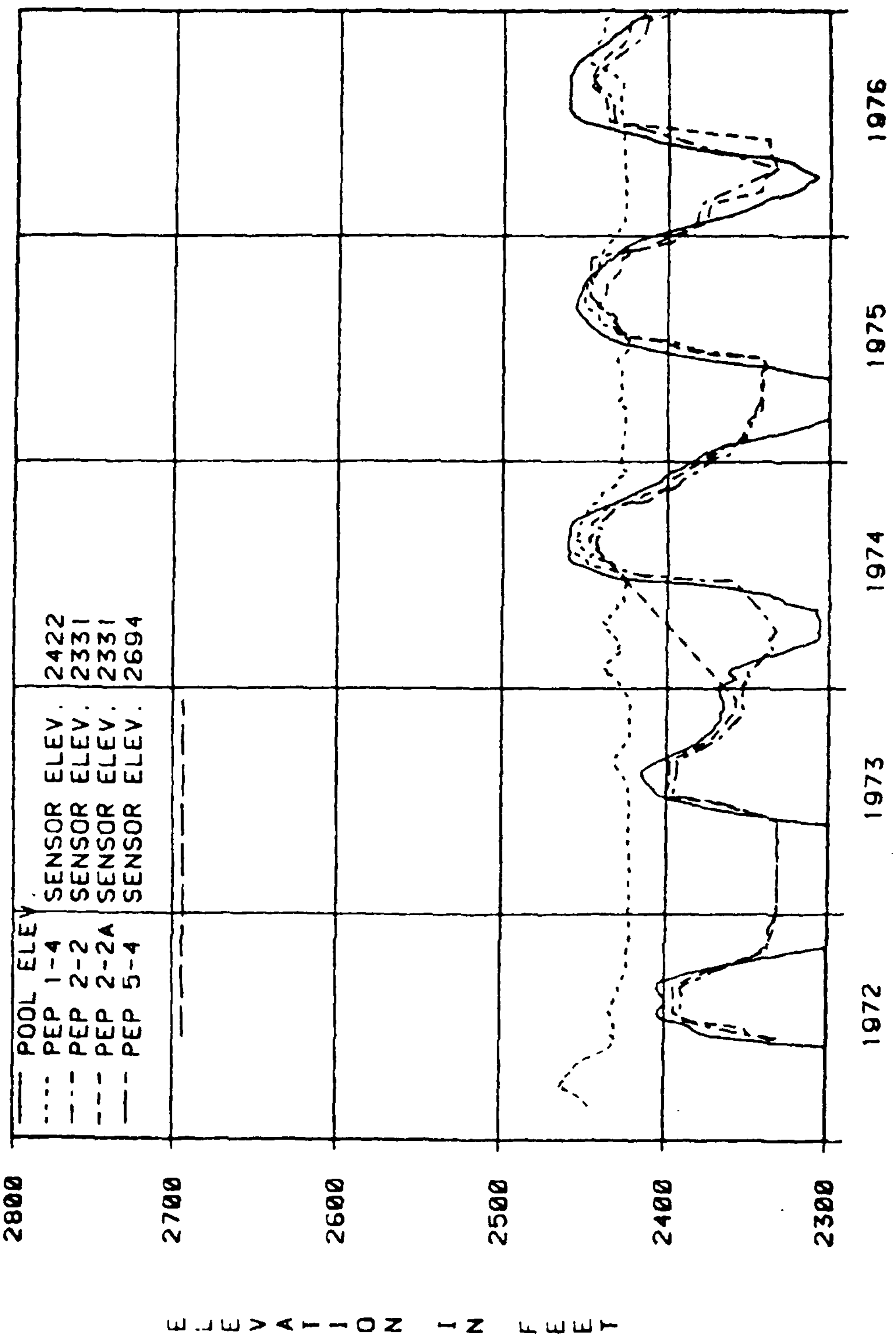
LIBBY LEFT BANK PIEZOMETERS (927 FAULT GROUP) 2/2



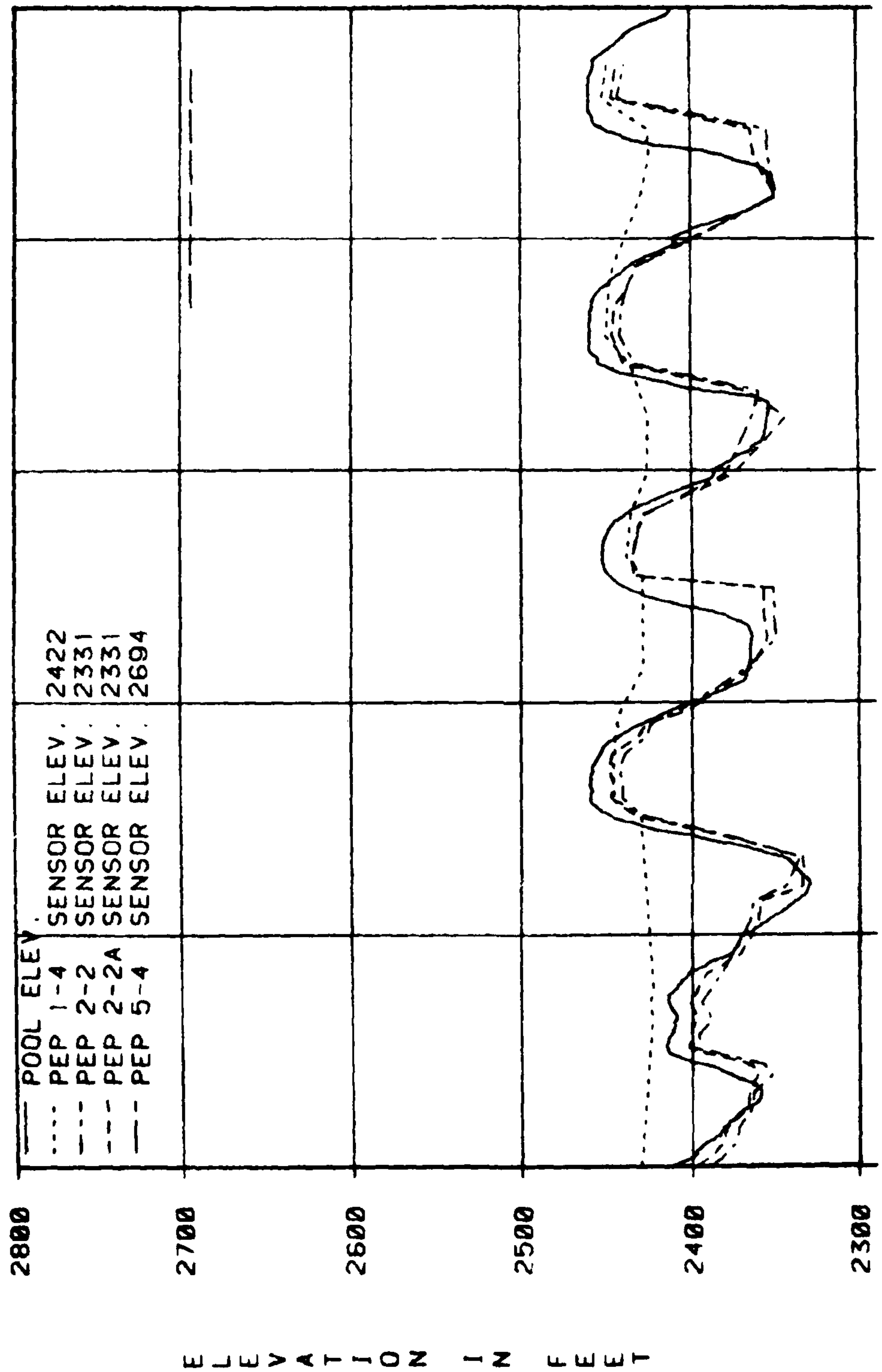
LIBBY LEFT BANK PIEZOMETERS (ZONE BETWEEN 927 & 928 FAULTS)



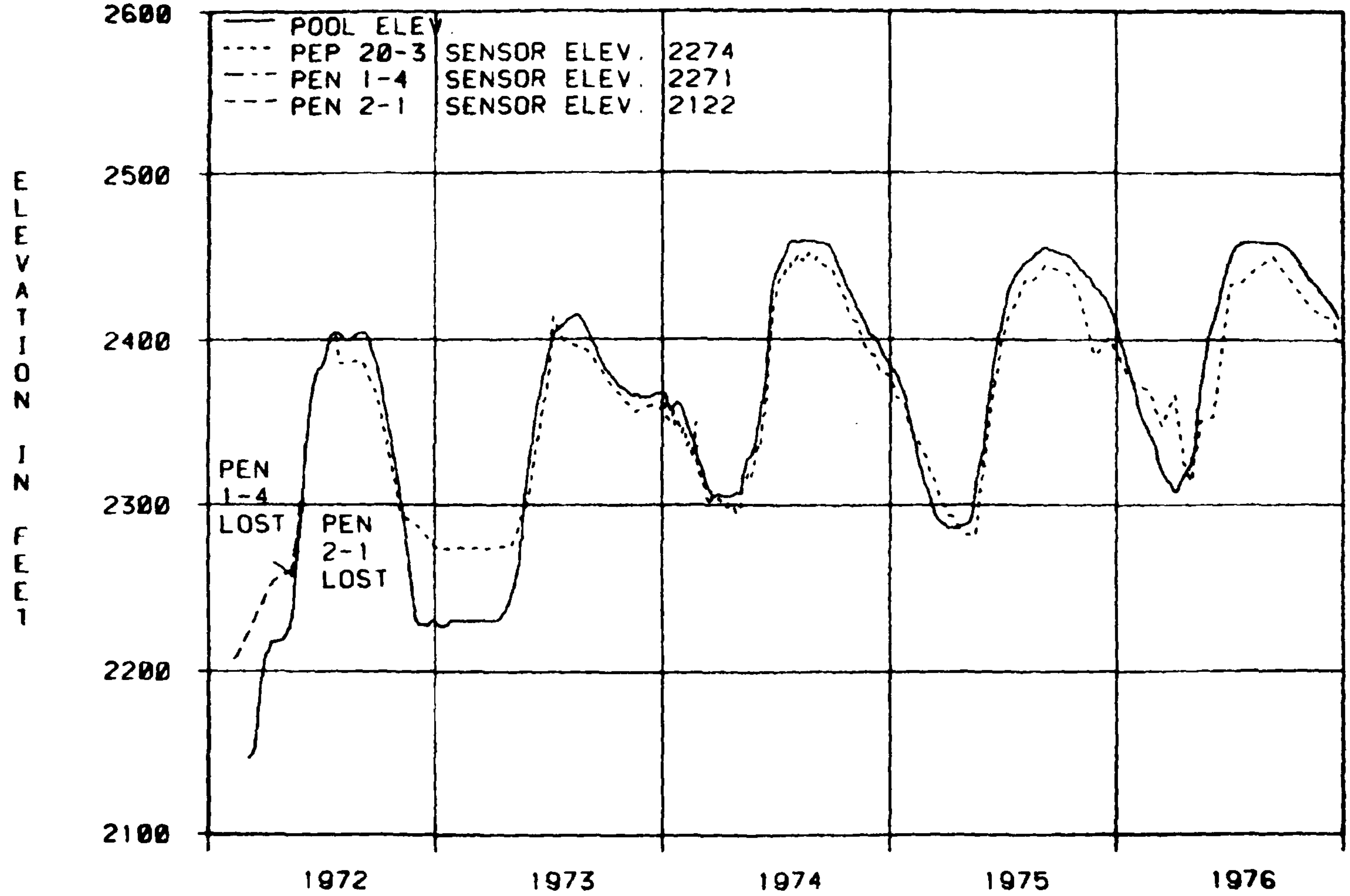
LIBBY LEFT BANK PIEZOMETERS (ZONE BETWEEN 927 & 928 FAULTS)



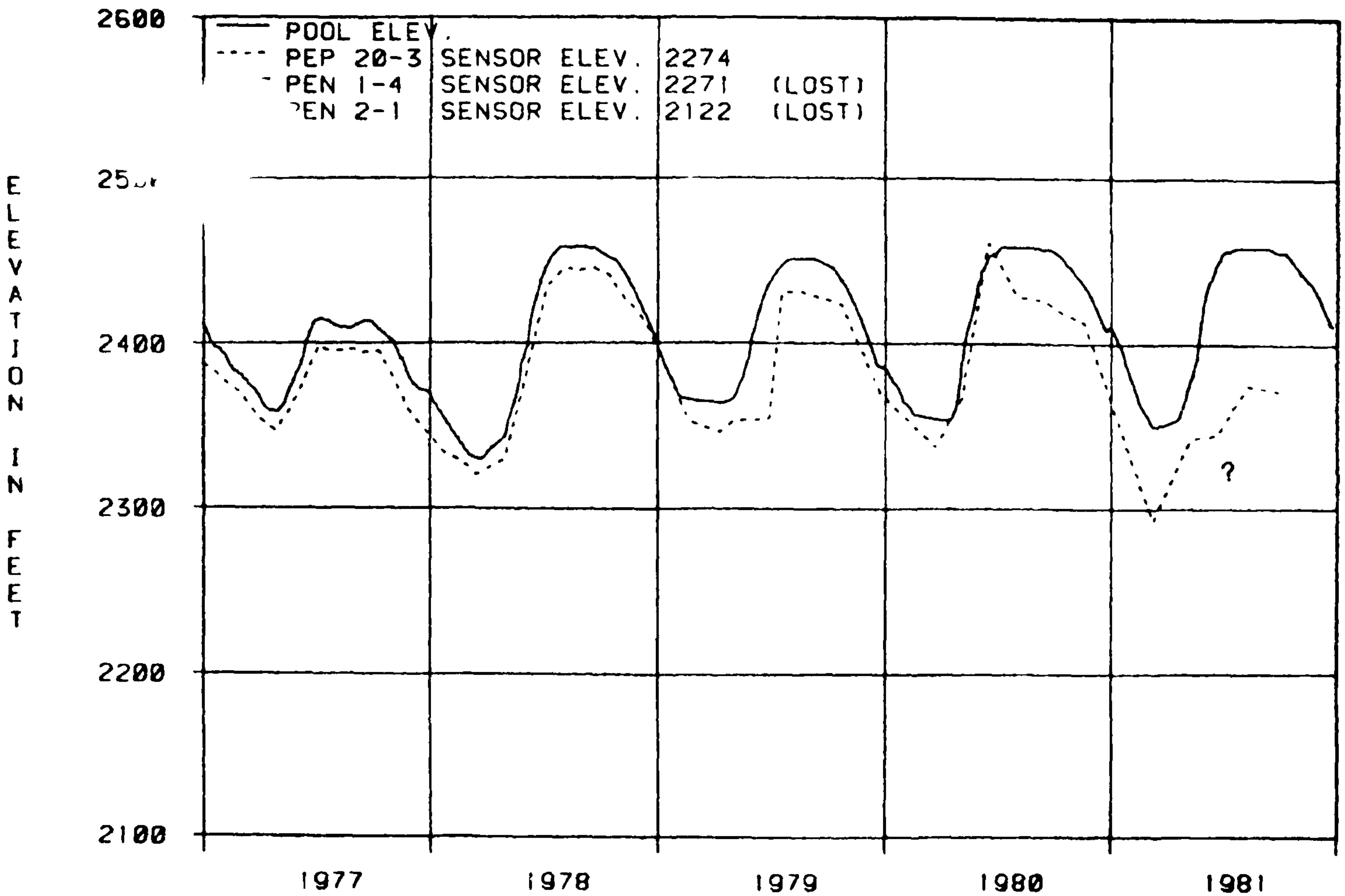
LIBBY LEFT BANK PIEZOMETERS (928 FAULT GROUP) 1/2



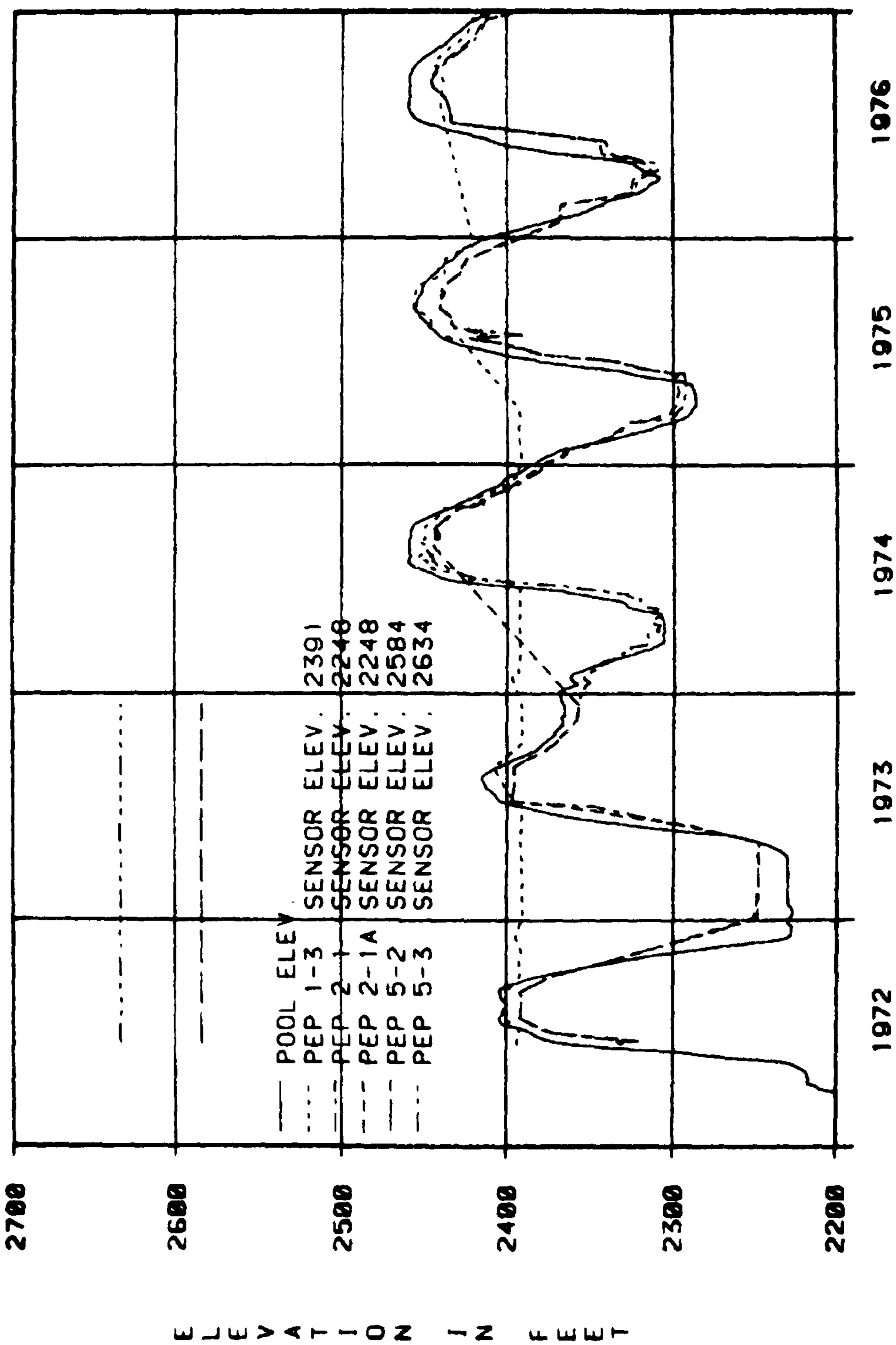
LIBBY LEFT BANK PIEZOMETERS (928 FAULT GROUP) 1/2



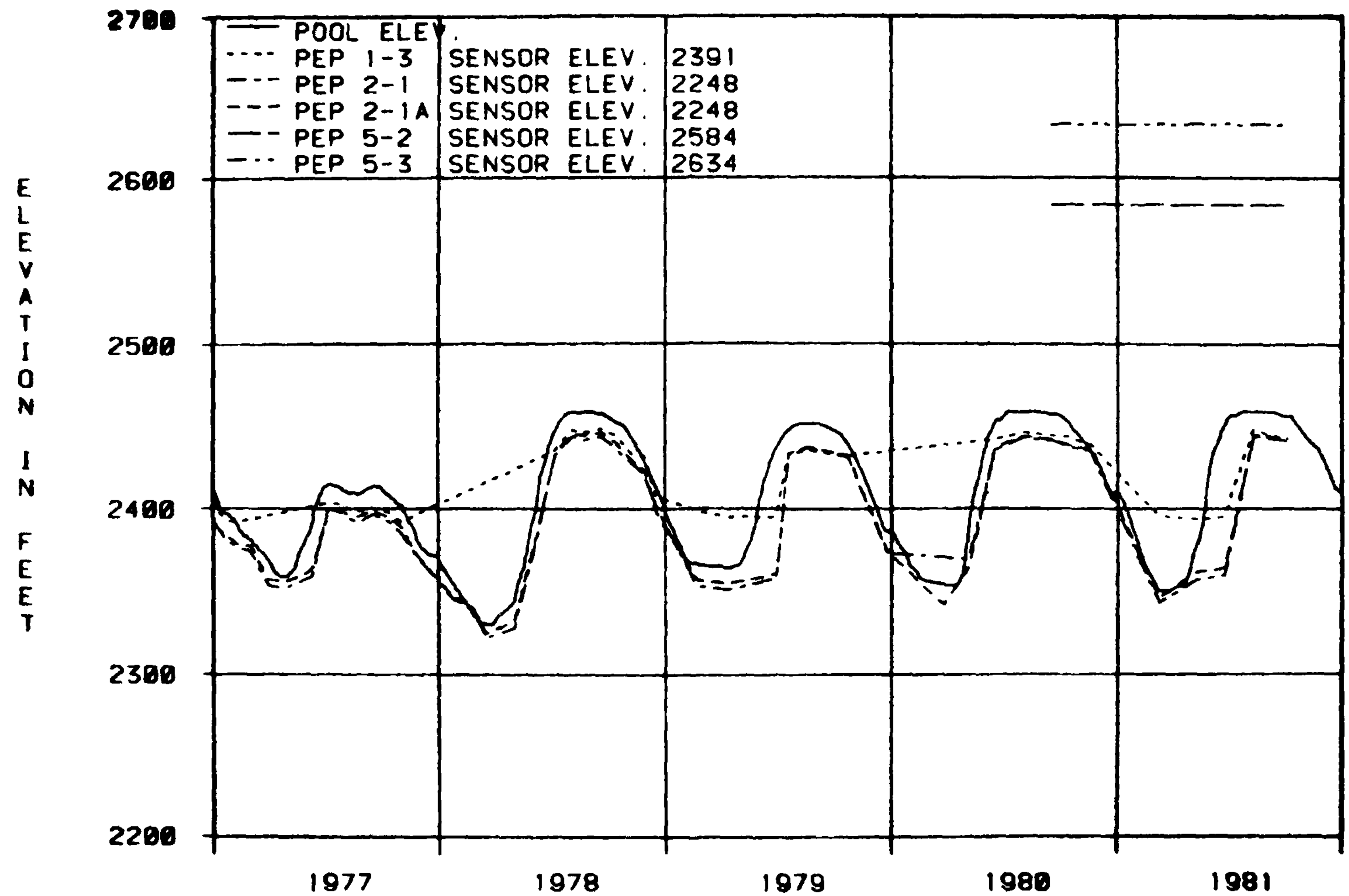
LIBBY LEFT BANK PIEZOMETERS (928 FAULT GROUP) 2/2



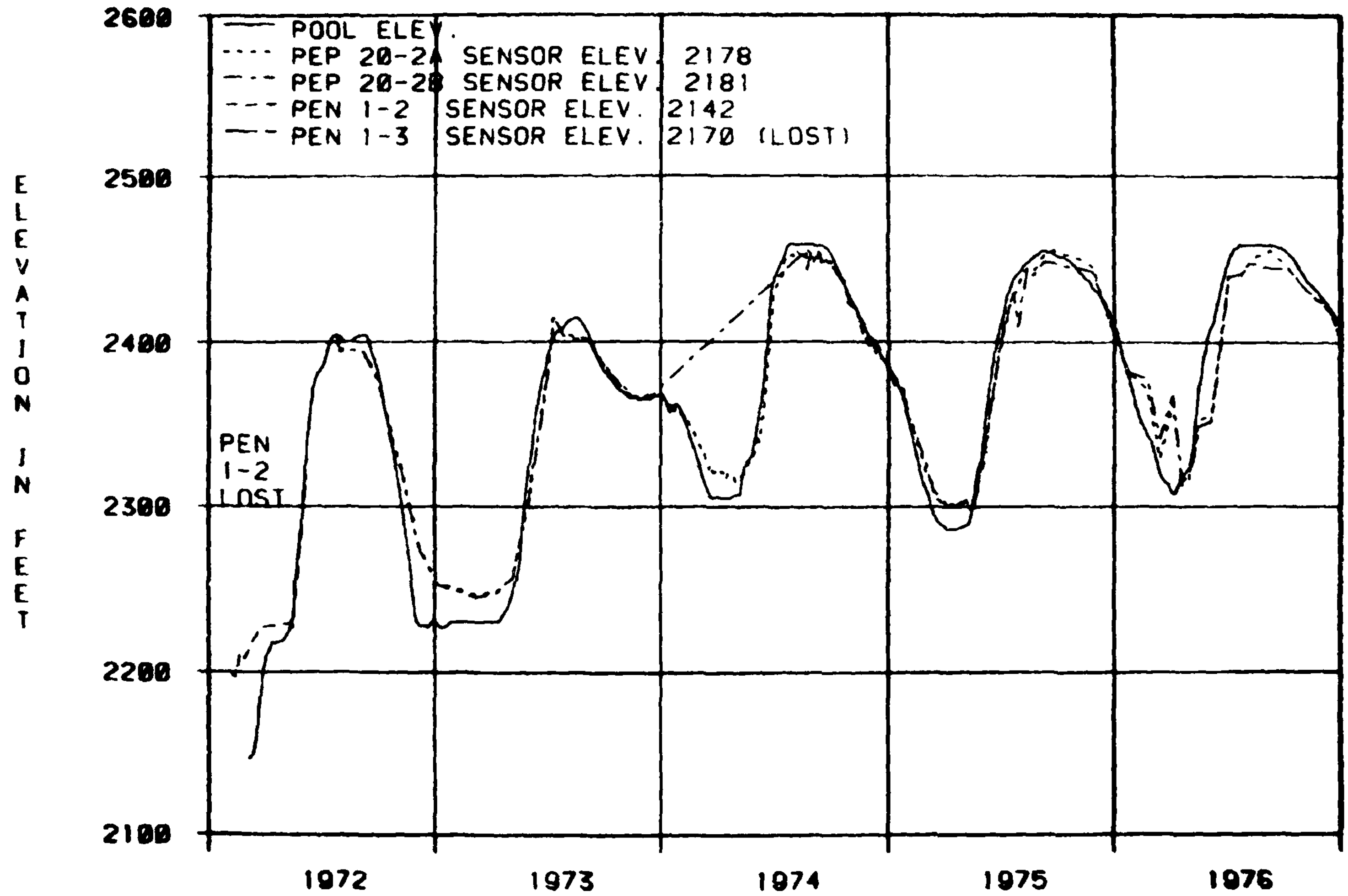
LIBBY LEFT BANK PIEZOMETERS (1928 FAULT GROUP) 2/2



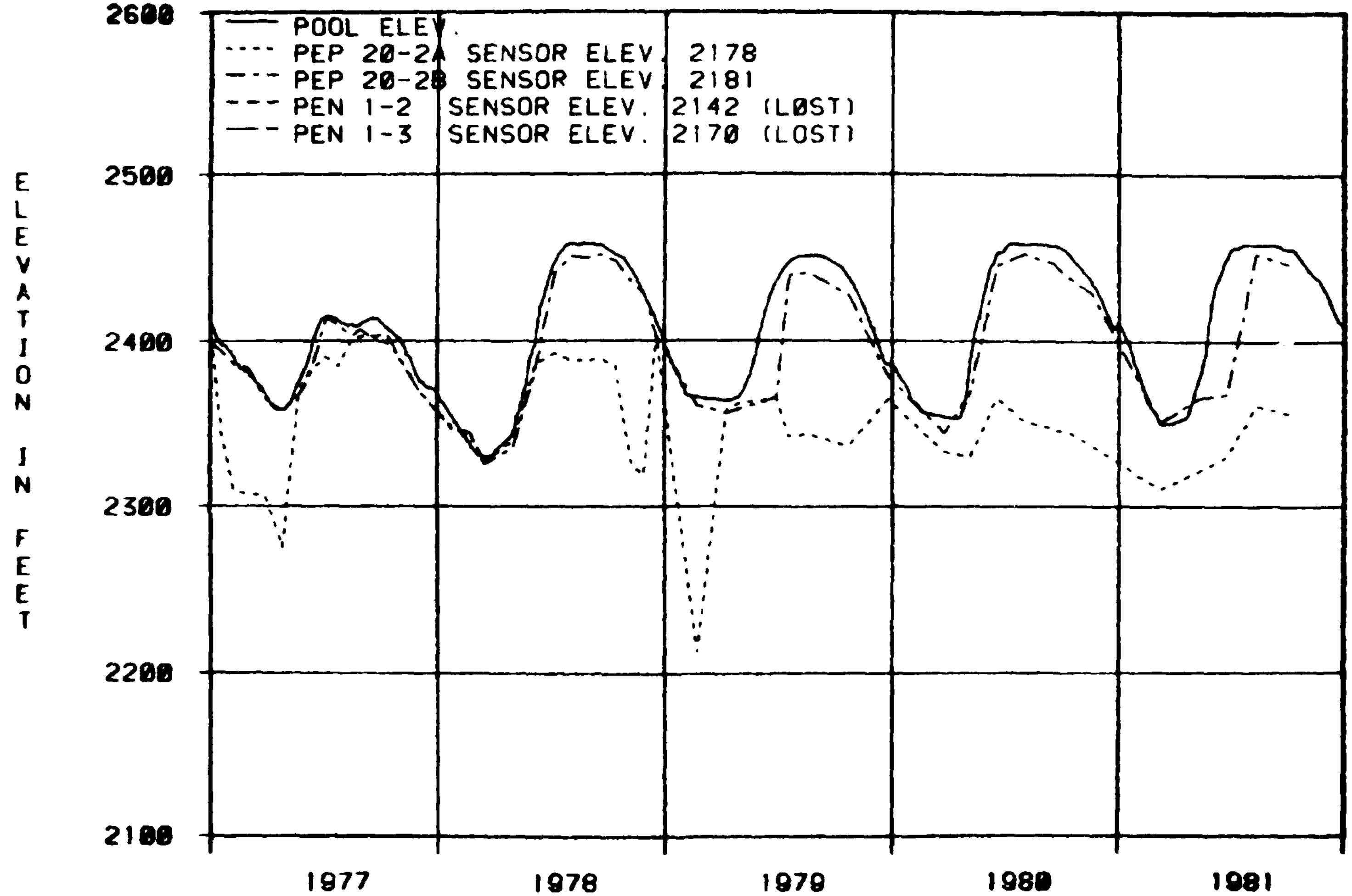
LIBBY LEFT BANK PIEZOMETERS (HIDDEN FAULT) 1/2



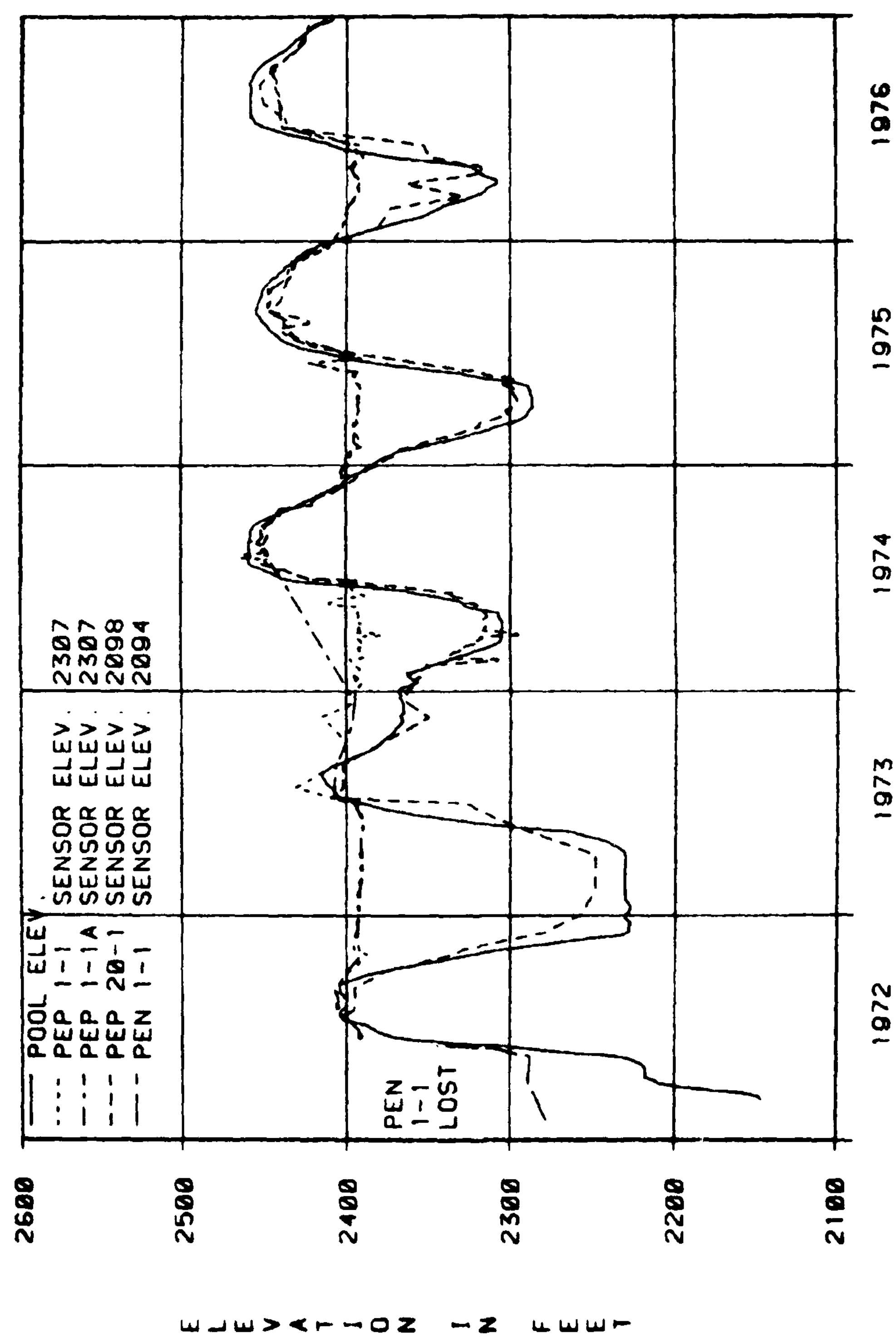
LIBBY LEFT BANK PIEZOMETERS (HIDDEN FAULT) 1/2



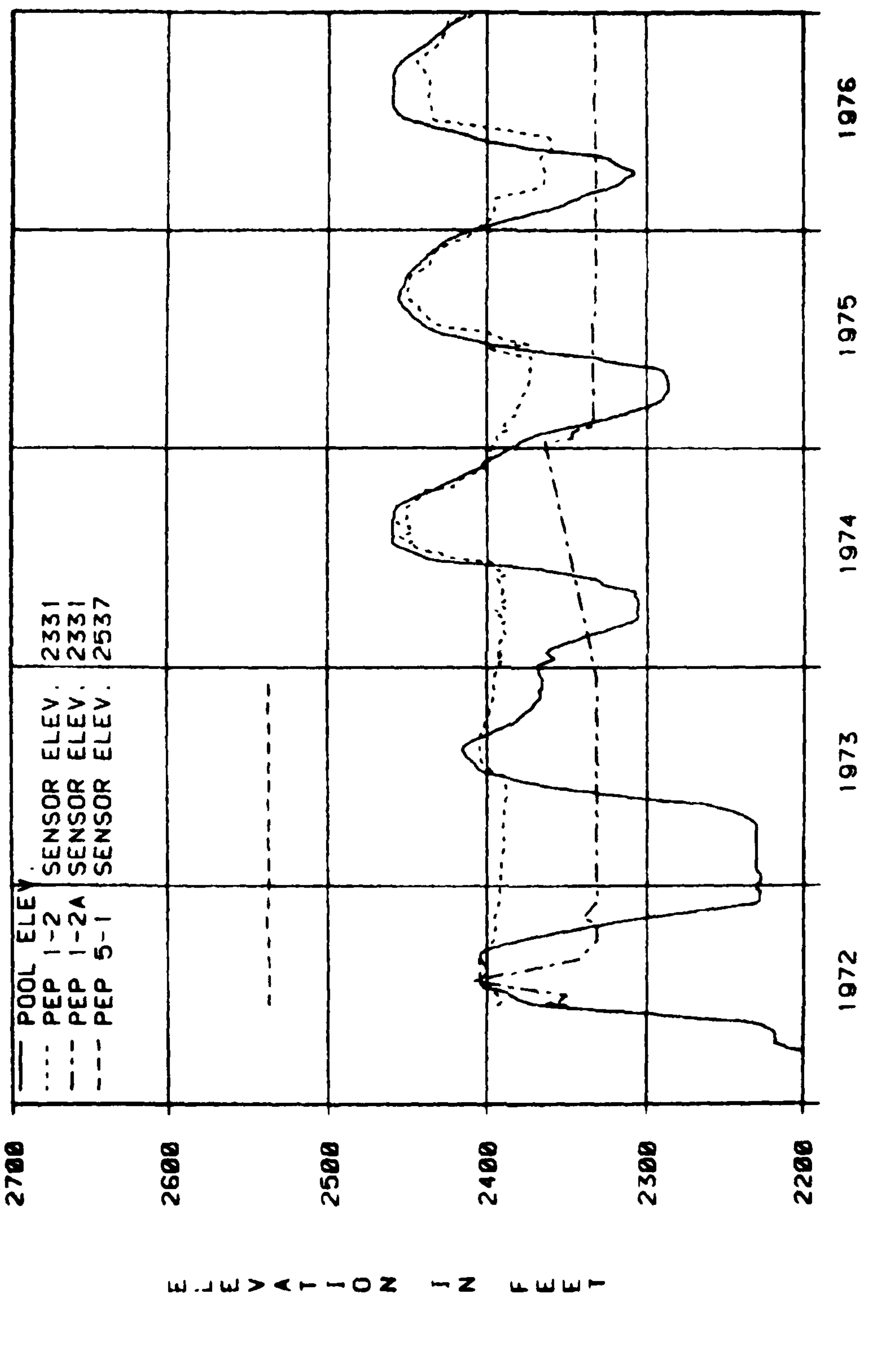
LIBBY LEFT BANK PIEZOMETERS (HIDDEN FAULT) 2/2



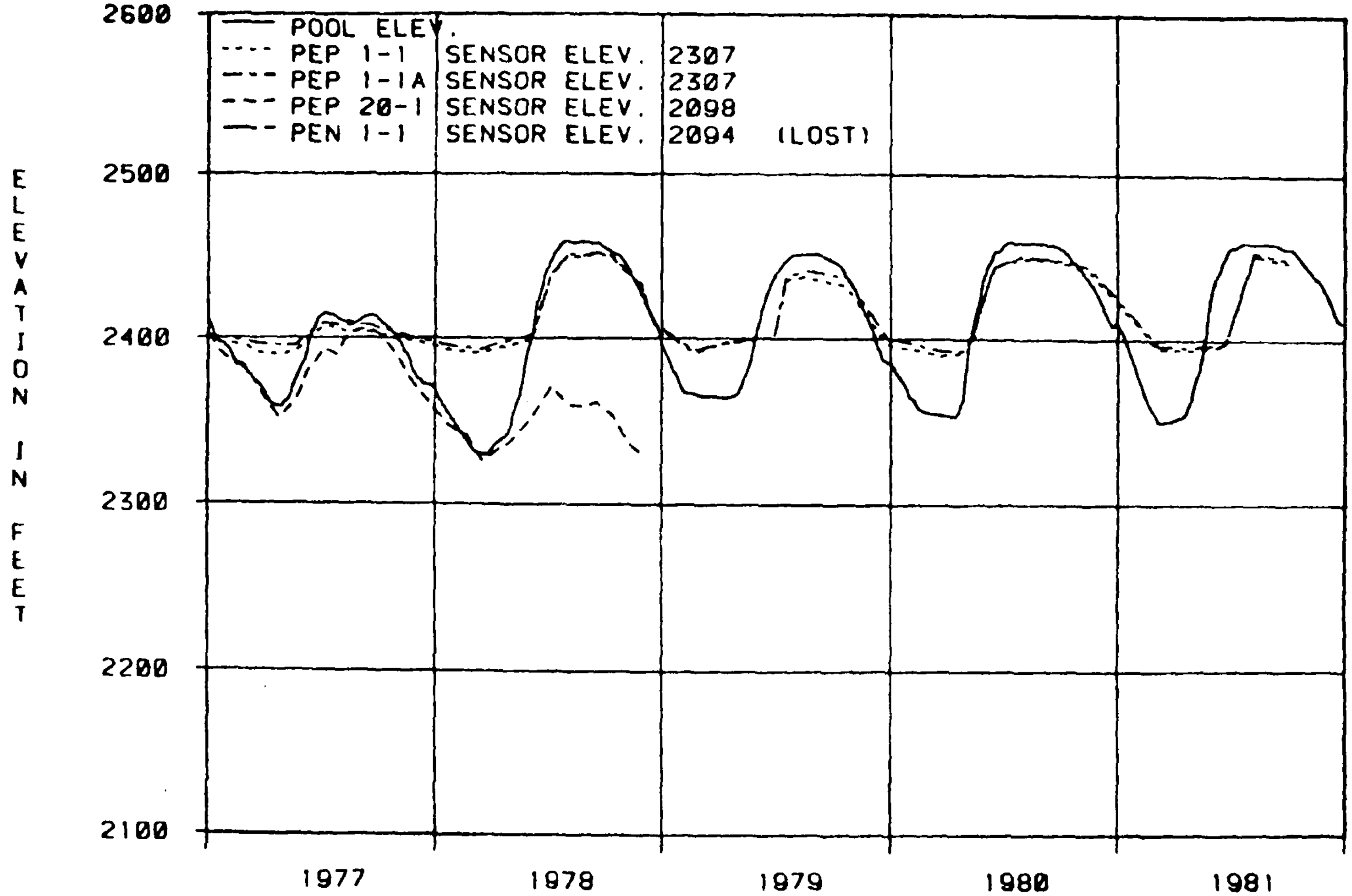
LIBBY LEFT BANK PIEZOMETERS (HIDDEN FAULT) 2/2



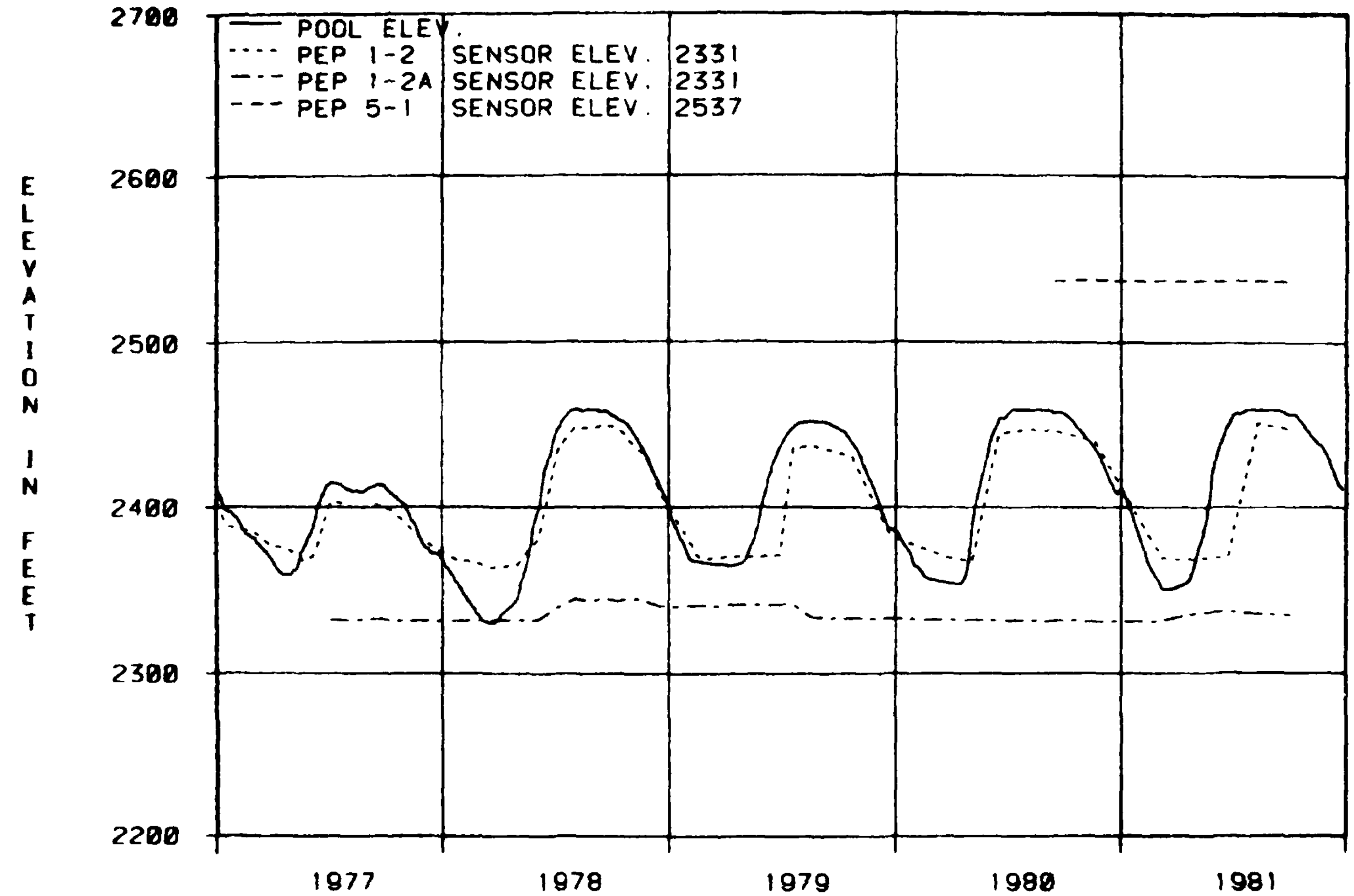
LIBBY LEFT BANK PIEZOMETERS (930 FAULT GROUP) 1/2



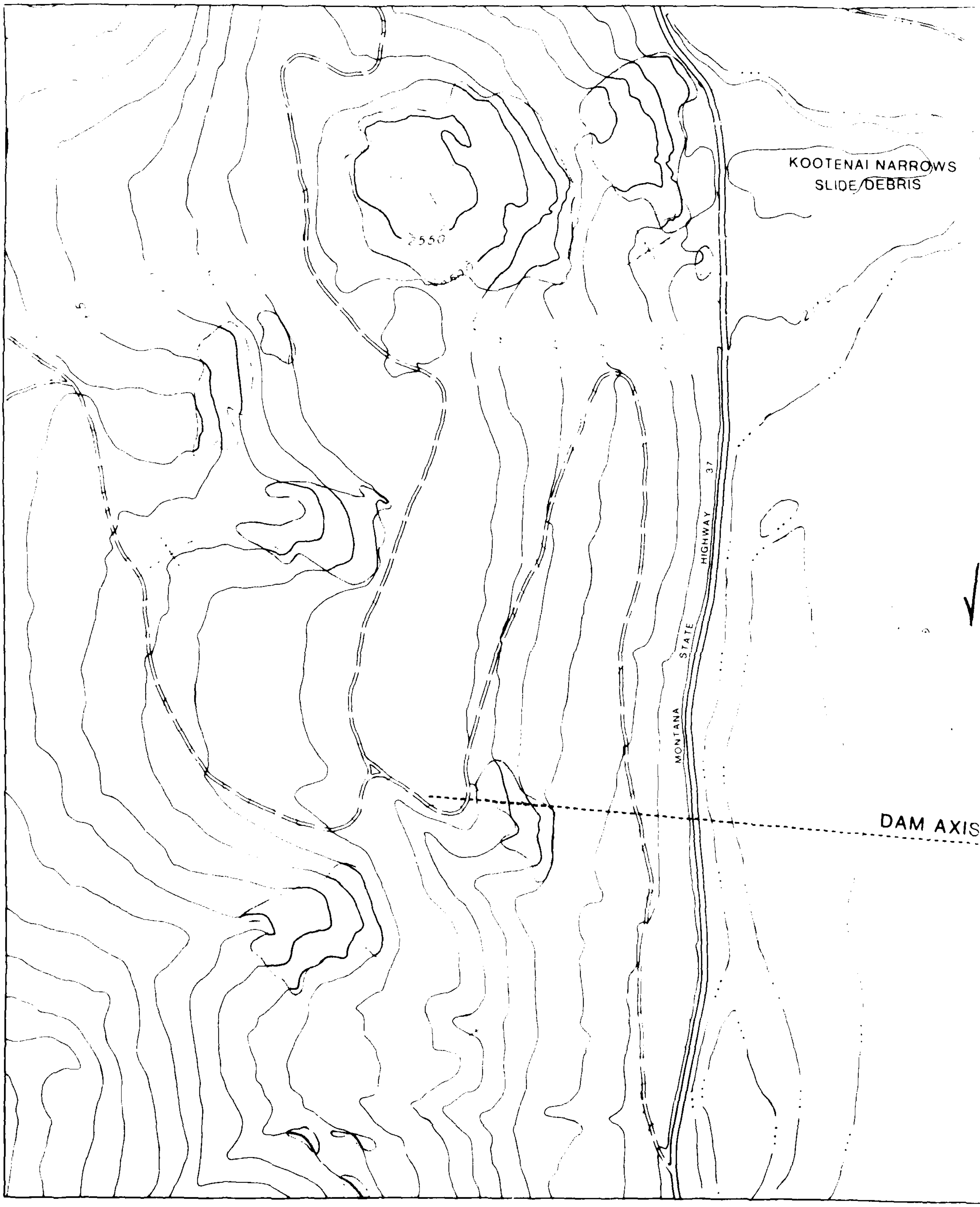
LIBBY LEFT BANK PIEZOMETERS (1930 FAULT GROUP) 2/2

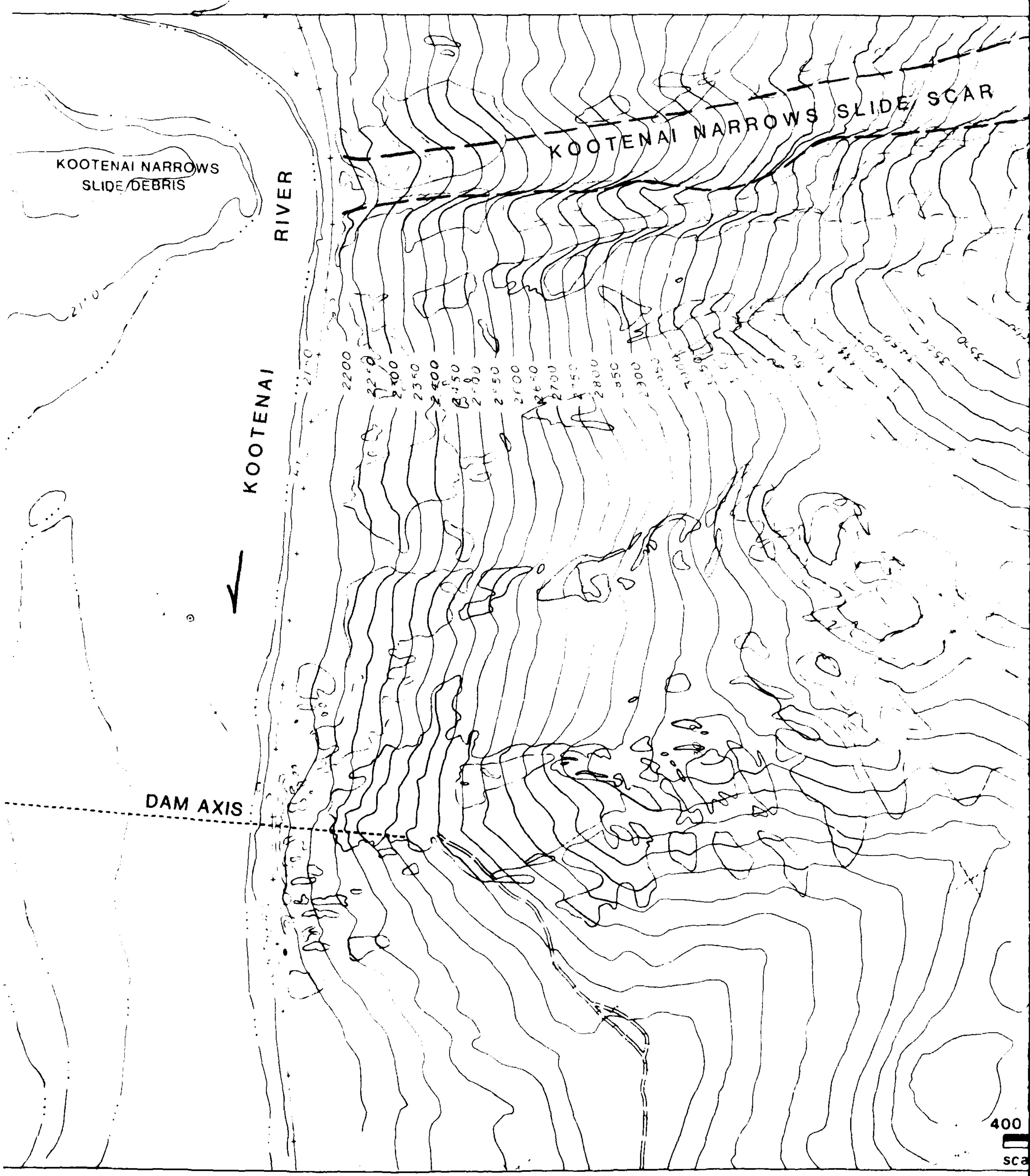


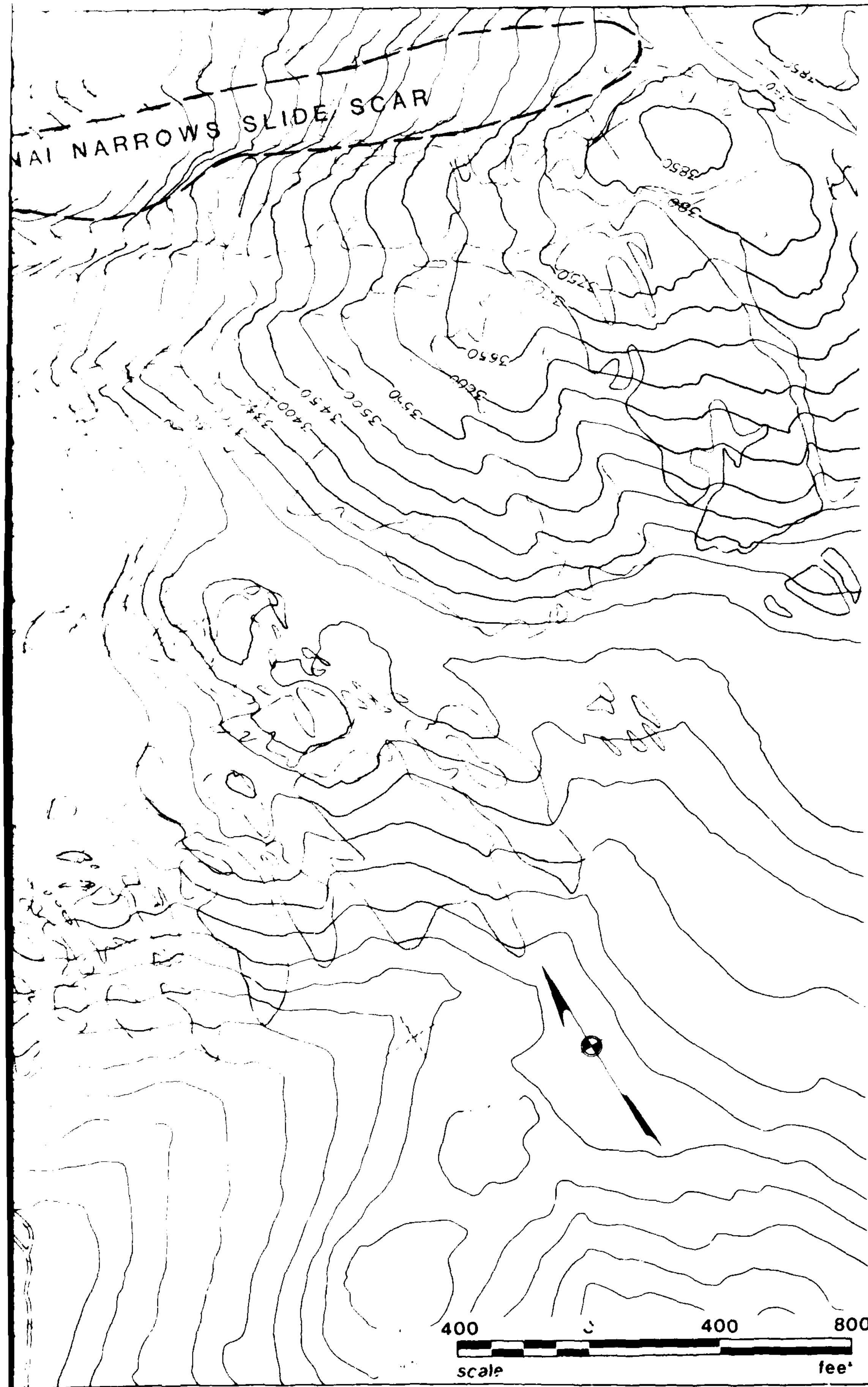
LIBBY LEFT BANK PIEZOMETERS (930 FAULT GROUP) 1/2



LIBBY LEFT BANK PIEZOMETERS (930 FAULT GROUP) 2/2


KOOTENAI NARROWS
SLIDE DEBRIS
2550
MONTANA STATE HIGHWAY 37
DAM AXIS


KOOTENAI NARROWS SLIDE SCAR
KOOTENAI NARROWS
SLIDE DEBRIS
KOOTENAI
RIVER
2200
2350
DAM AXIS
400



LEGEND

E

KOOTENAI RIVEF

LIBBY DAM AND

PROJ

LEFT BAN
PRE-CONSTRUCTIC
AND BEDROCK

LEGEND

4

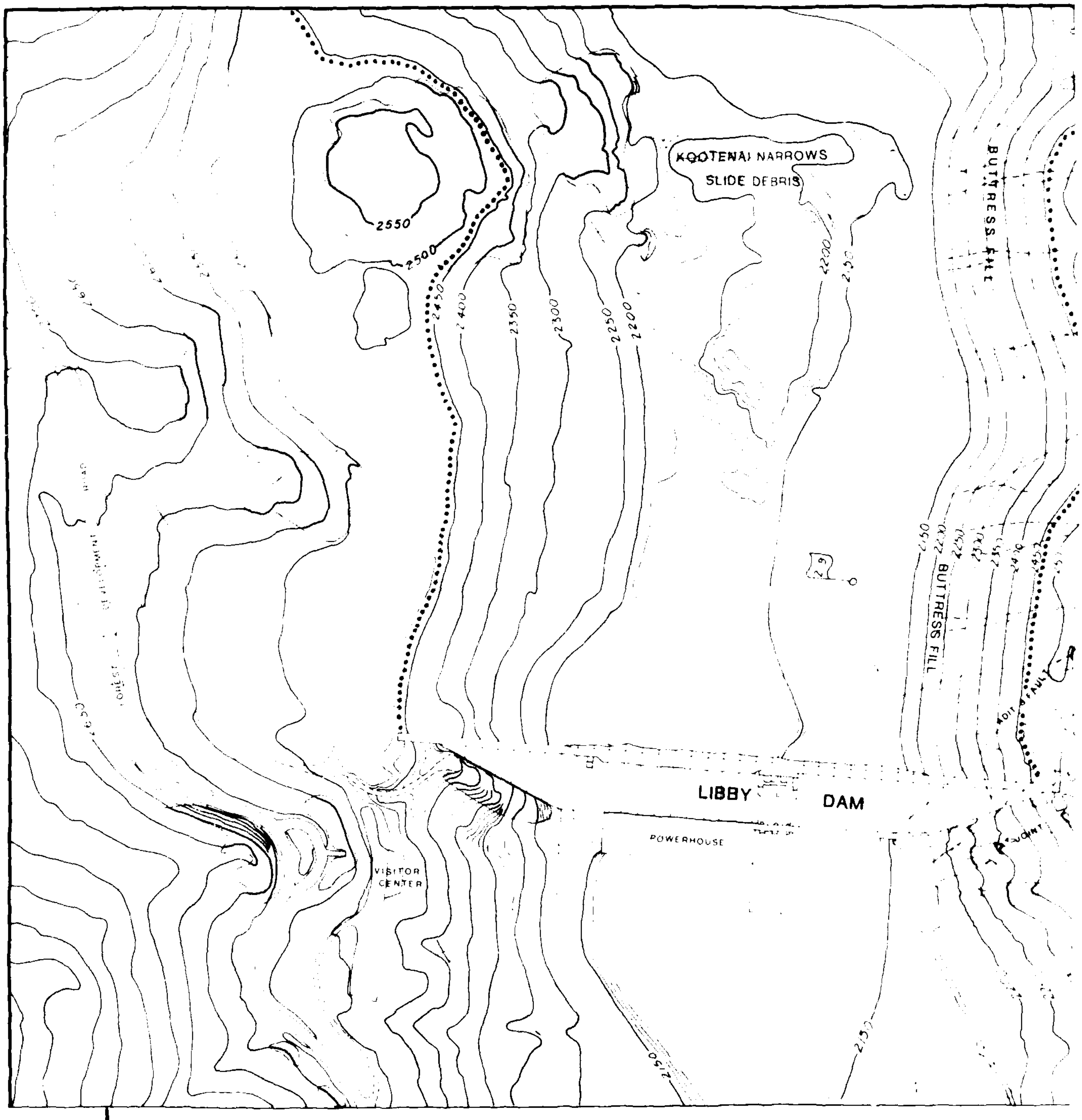
BEDROCK OUTCROP

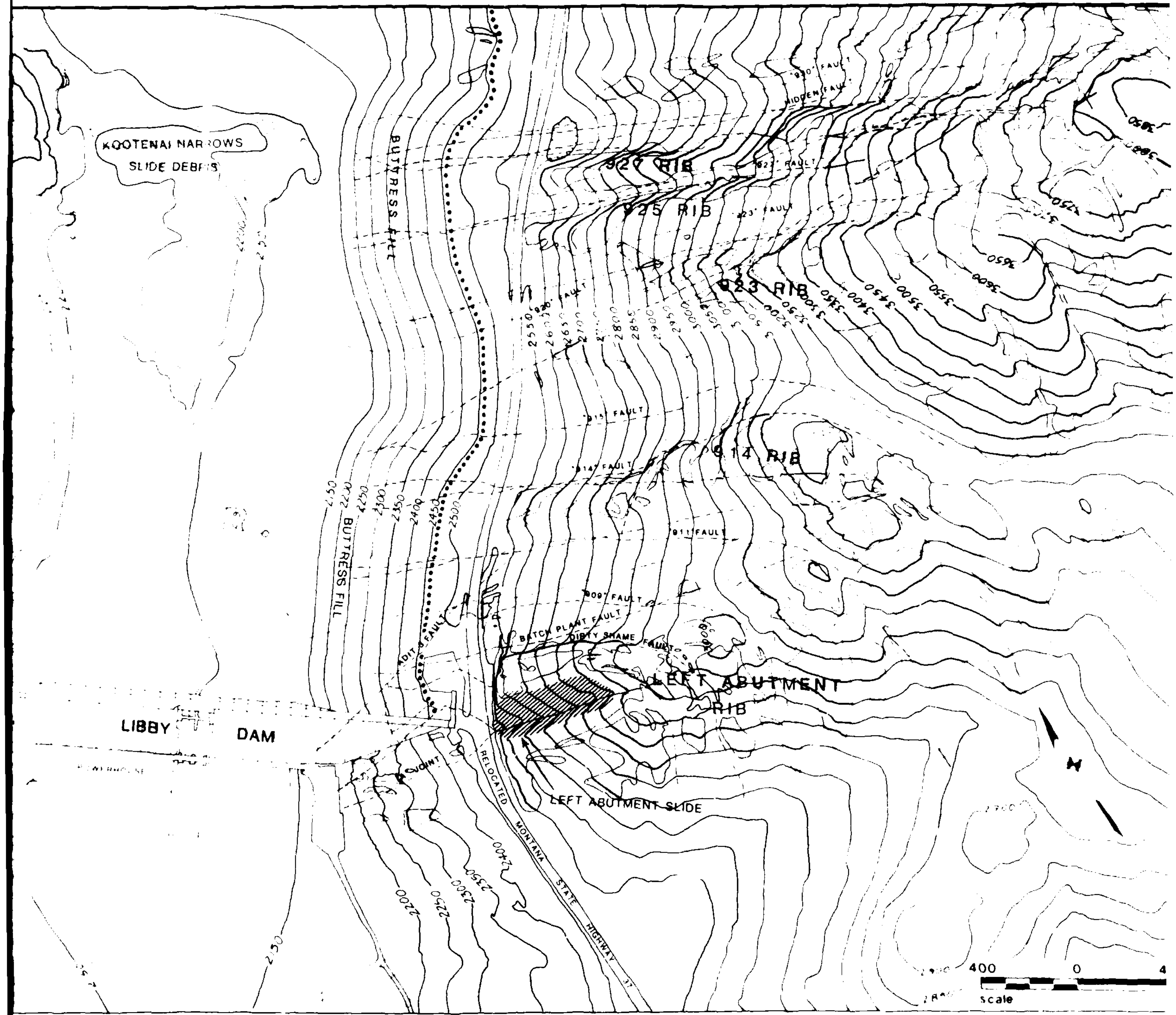
KOOTENAI RIVER MONTANA

LIBBY DAM AND LAKE KOOCANUSA PROJECT

LEFT BANK SLOPE PRE-CONSTRUCTION TOPOGRAPHY AND BEDROCK OUTCROPS

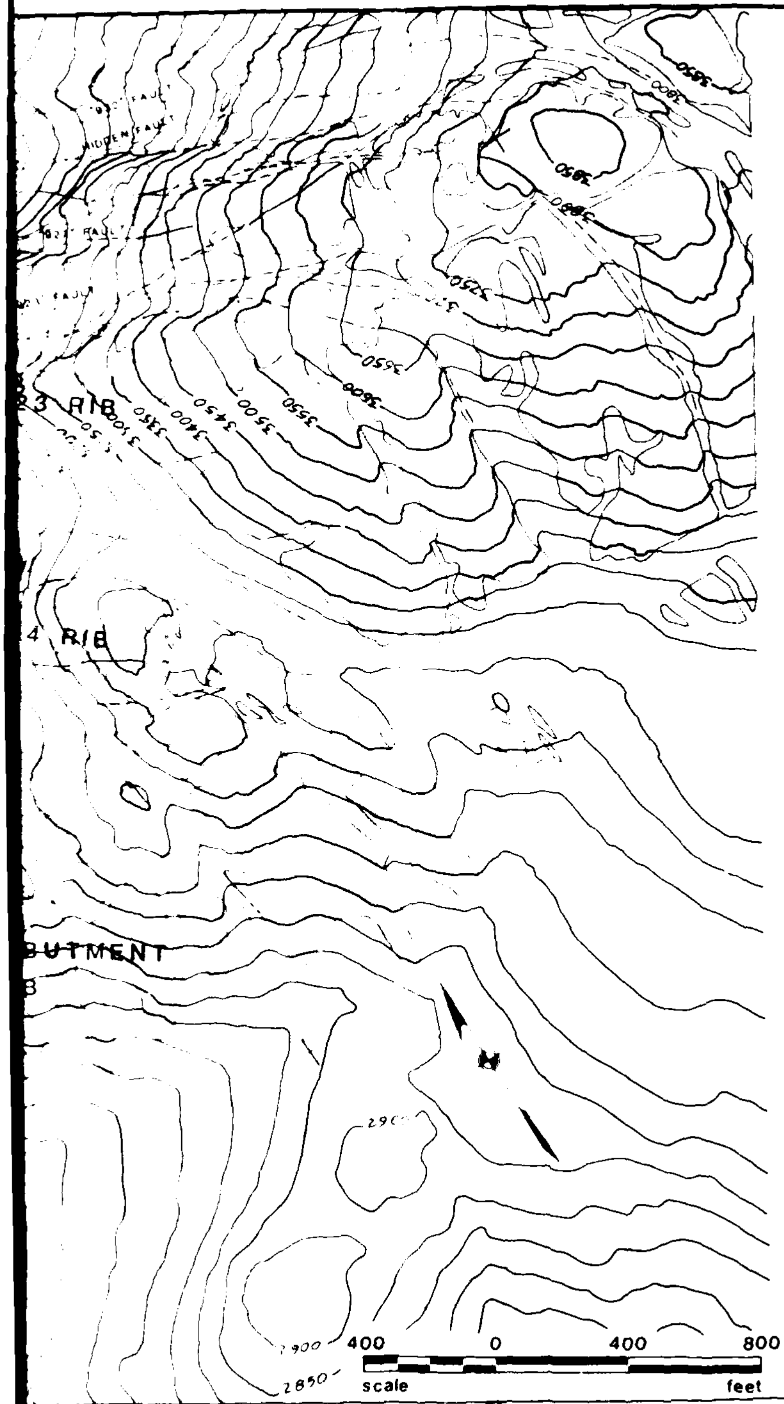
PLATE 1


KOOTENAI NARROWS
SLIDE DEBRIS
2550
2500
2450
2400
2350
2300
2250
2200
BUTTRESS FILL
BUTTRESS FILL
LIBBY
DAM
POWERHOUSE
VISITOR
CENTER



KOOTENAI NARROWS
SLIDE DEBRIS
BUTTRESS FILL
BUTTRESS FILL
927 RIB
925 RIB
923 RIB
914 RIB
920' FAULT
HIDDEN FAULT
923' FAULT
915' FAULT
914' FAULT
911 FAULT
909' FAULT
BATCH PLANT FAULT
DIRTY SHAME FAULT
ADIT 9 FAULT
LEFT ABUTMENT
RIB
LEFT ABUTMENT SLIDE
LIBBY
DAM
JOINT
RELOCATED MONTANA STATE HIGHWAY 37
400
0
scale

2



LEGEND

BEDROCK OUTCROP

MAJOR ROCK FRACTURES

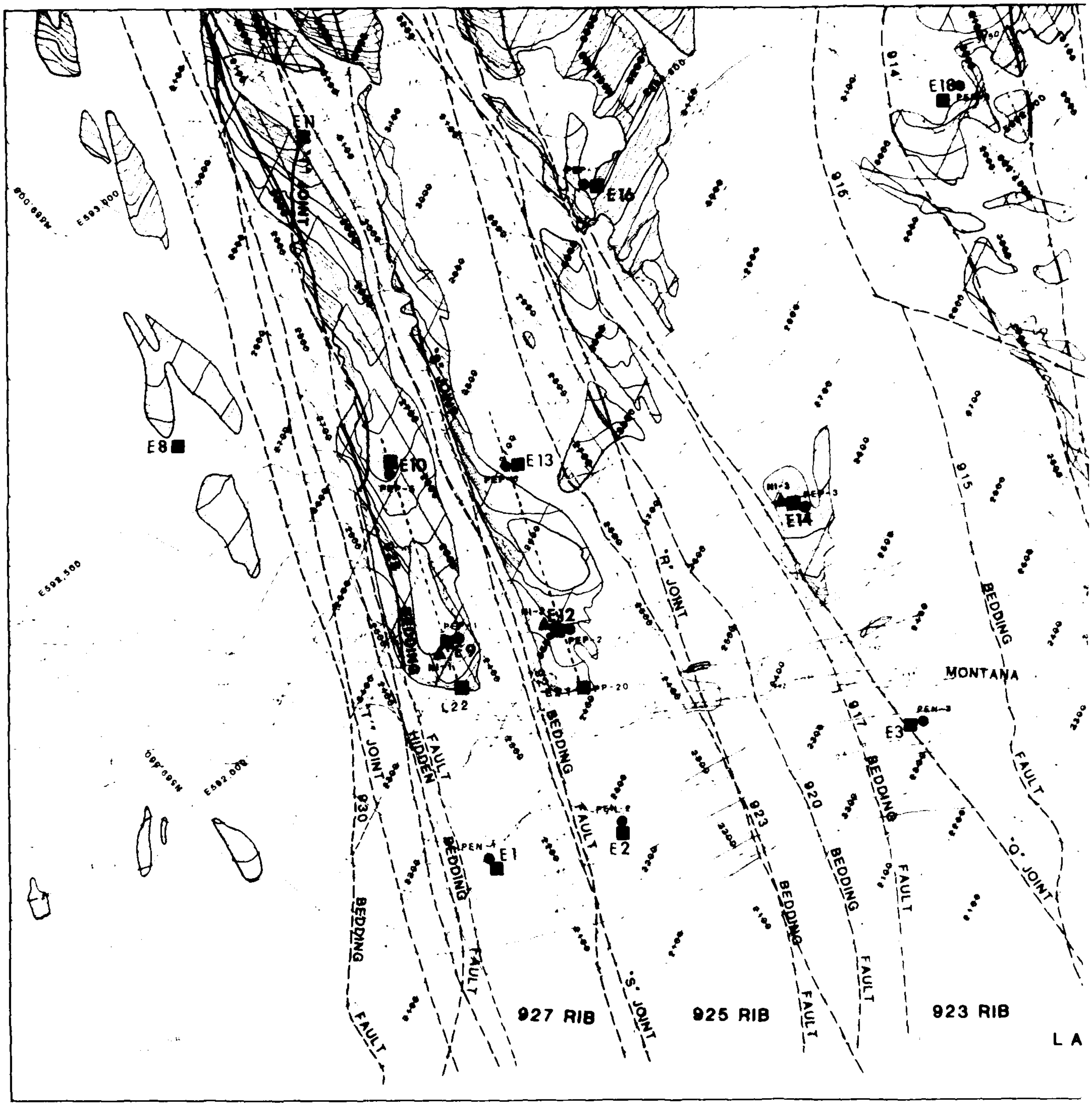
MAXIMUM RESERVOIR

KOOTENAI RIVER MONTANA

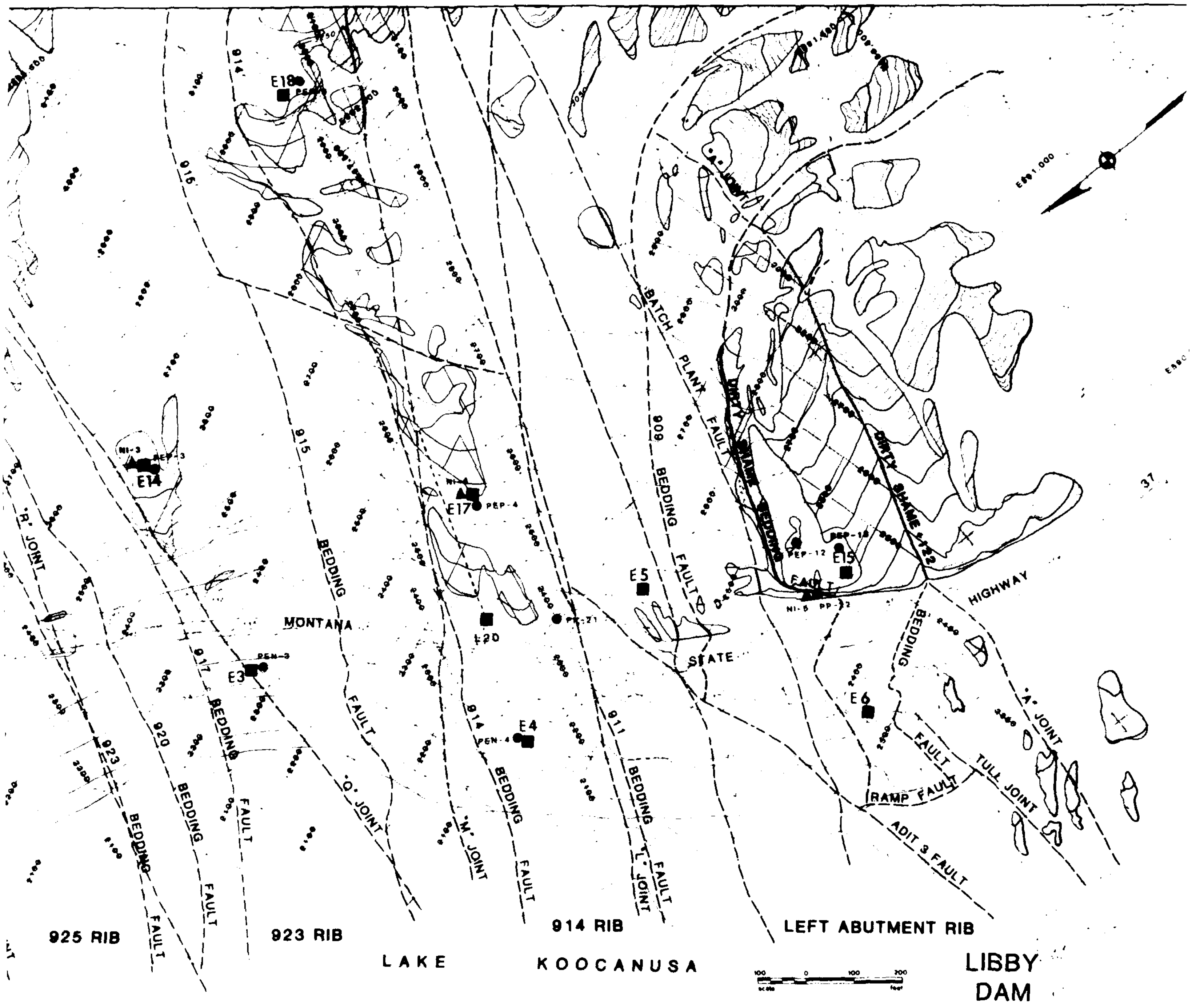
LIBBY DAM AND LAKE KOOCANUSA PROJECT

LEFT BANK SLOPE AREAL GEOLOGY

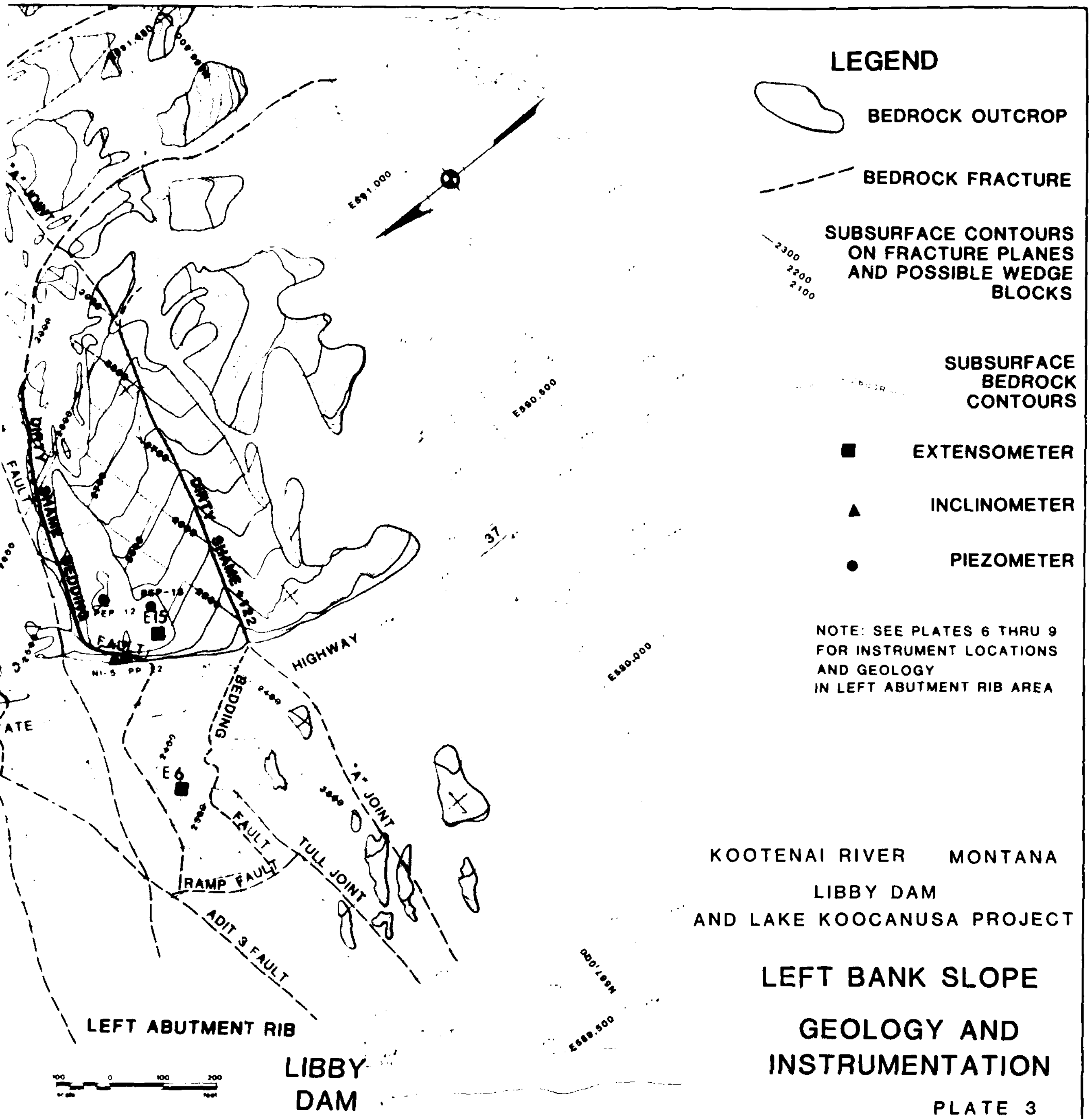
PLATE 2



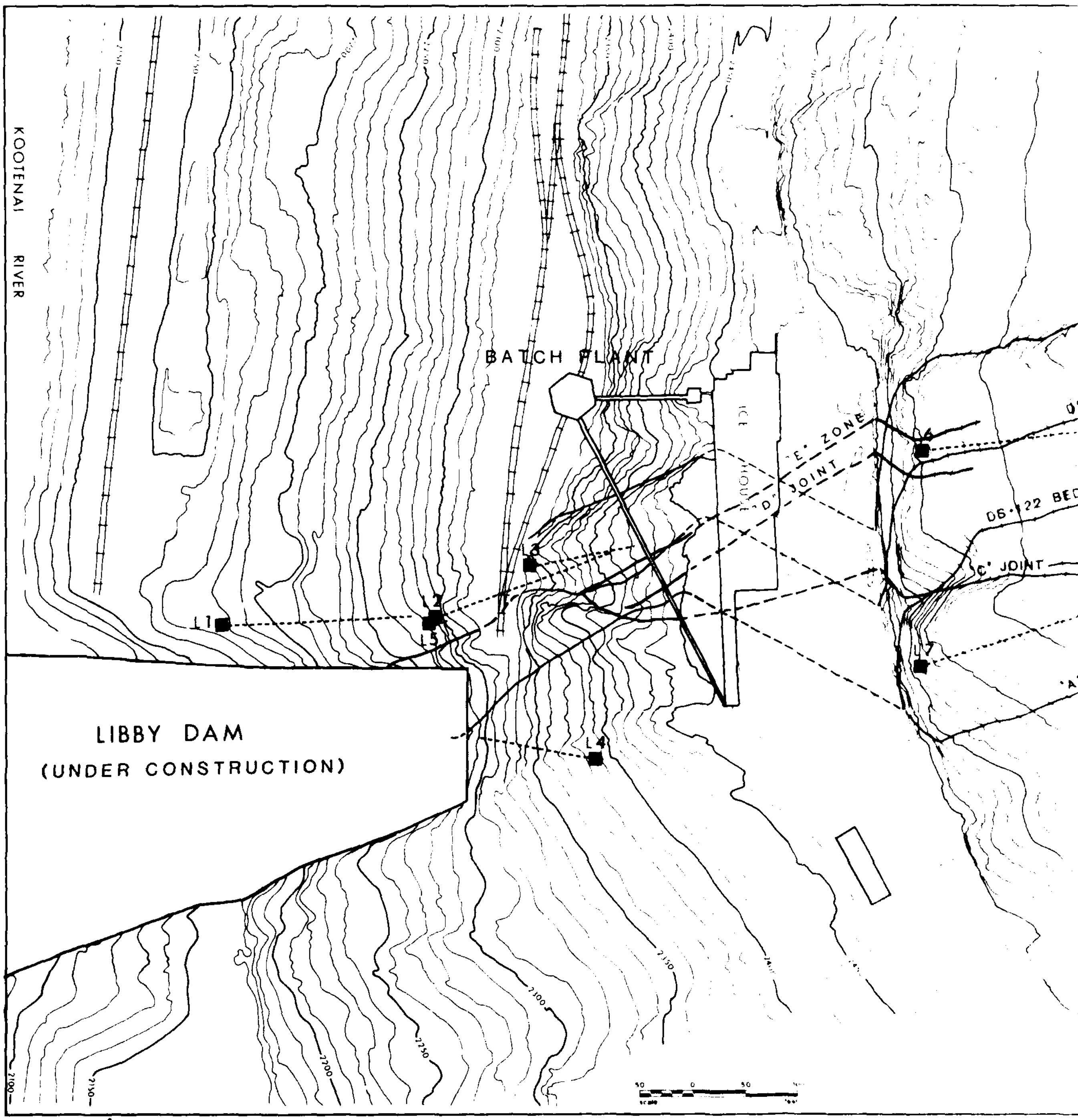
E8
E10
E11
E13
E16
E18
E14
E12
E9
L22
E1
E2
E3
PEN-4
PEN-2
PEN-3
E593,000
E592,500
E592,000
'R' JOINT
'S' JOINT
'Q' JOINT
'T' JOINT
HIDDEN
FAULT
BEDDING
MONTANA
930
923
920
917
915
914
916
927 RIB
925 RIB
923 RIB
L A



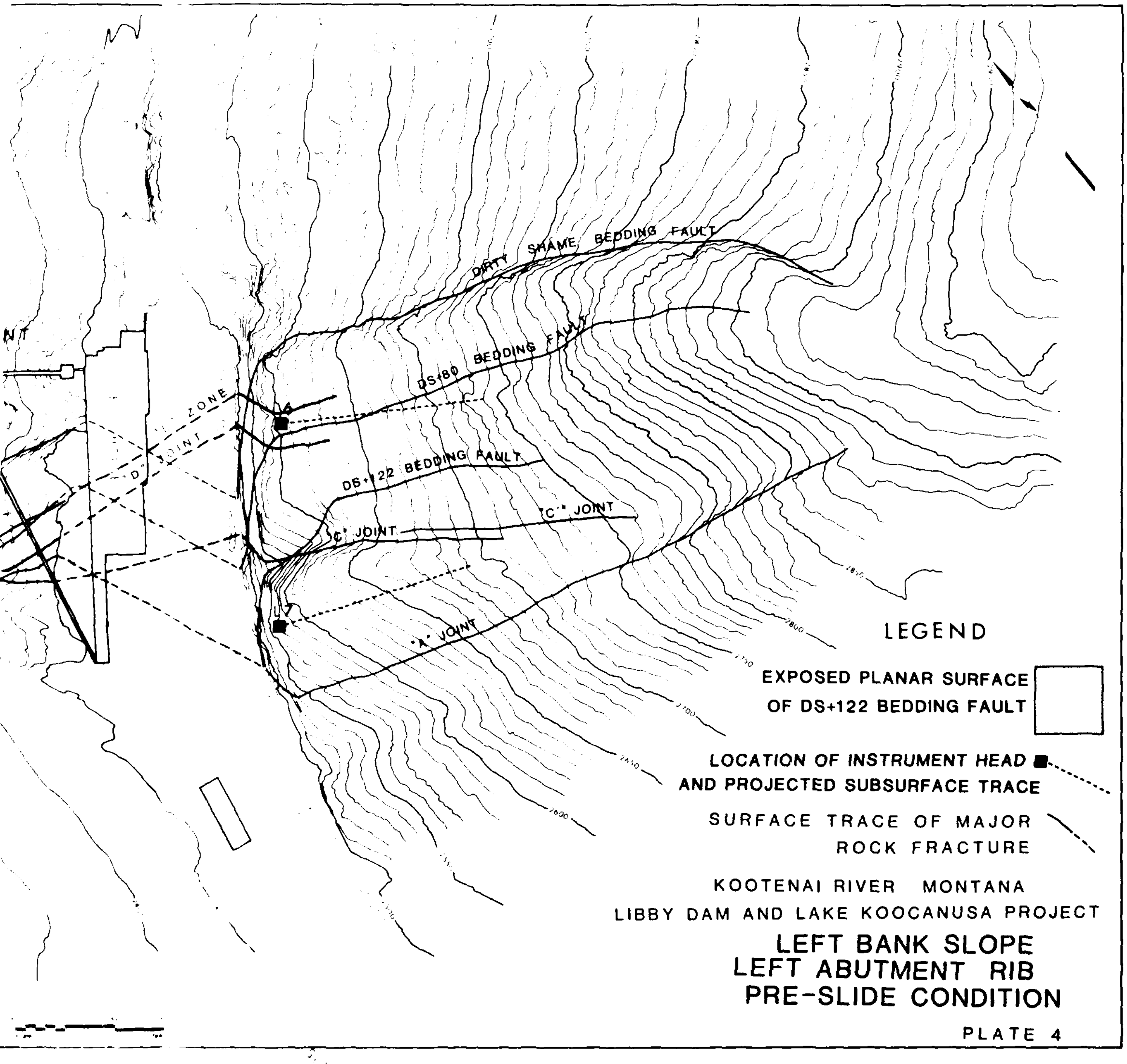
BATCH PLANT FAULT
909 BEDDING FAULT
915 BEDDING FAULT
916
914
'R' JOINT
MONTANA STATE HIGHWAY
917 BEDDING FAULT
920 BEDDING FAULT
923 BEDDING FAULT
'Q' JOINT
'M' JOINT
914 BEDDING FAULT
911 BEDDING FAULT
'L' JOINT
BEDDING FAULT
'A' JOINT
TULL JOINT
RAMP FAULT
ADIT 3 FAULT
E3
E4
E5
E6
E14
E15
E17
E18
E20
925 RIB
923 RIB
914 RIB
LEFT ABUTMENT RIB
LAKE KOOCANUSA
LIBBY DAM


LEGEND
BEDROCK OUTCROP
BEDROCK FRACTURE
SUBSURFACE CONTOURS ON FRACTURE PLANES AND POSSIBLE WEDGE BLOCKS
2300
2200
2100
SUBSURFACE BEDROCK CONTOURS
EXTENSOMETER
INCLINOMETER
PIEZOMETER
NOTE: SEE PLATES 6 THRU 9 FOR INSTRUMENT LOCATIONS AND GEOLOGY IN LEFT ABUTMENT RIB AREA
E591,000
E590,500
E590,000
E589,500
N587,000
DIRTY SHAME FAULT
DIRTY SHAME BEDDING
DIRTY SHAME #22
FAULT
E15
PEP 12
HIGHWAY
BEDDING
E6
"A" JOINT
FAULT
TULL JOINT
RAMP FAULT
ADIT 3 FAULT
LEFT ABUTMENT RIB
LIBBY DAM
KOOTENAI RIVER MONTANA
LIBBY DAM
AND LAKE KOOCANUSA PROJECT
LEFT BANK SLOPE
GEOLOGY AND INSTRUMENTATION
PLATE 3

3



KOOTENAI RIVER
BATCH PLANT
ICE HOUSE
'E' ZONE
'D' JOINT
DS-122 BED
'C' JOINT
'A'
L1
L2
L3
L4
L5
L6
L7
LIBBY DAM
(UNDER CONSTRUCTION)
2100
2150
2200
2250

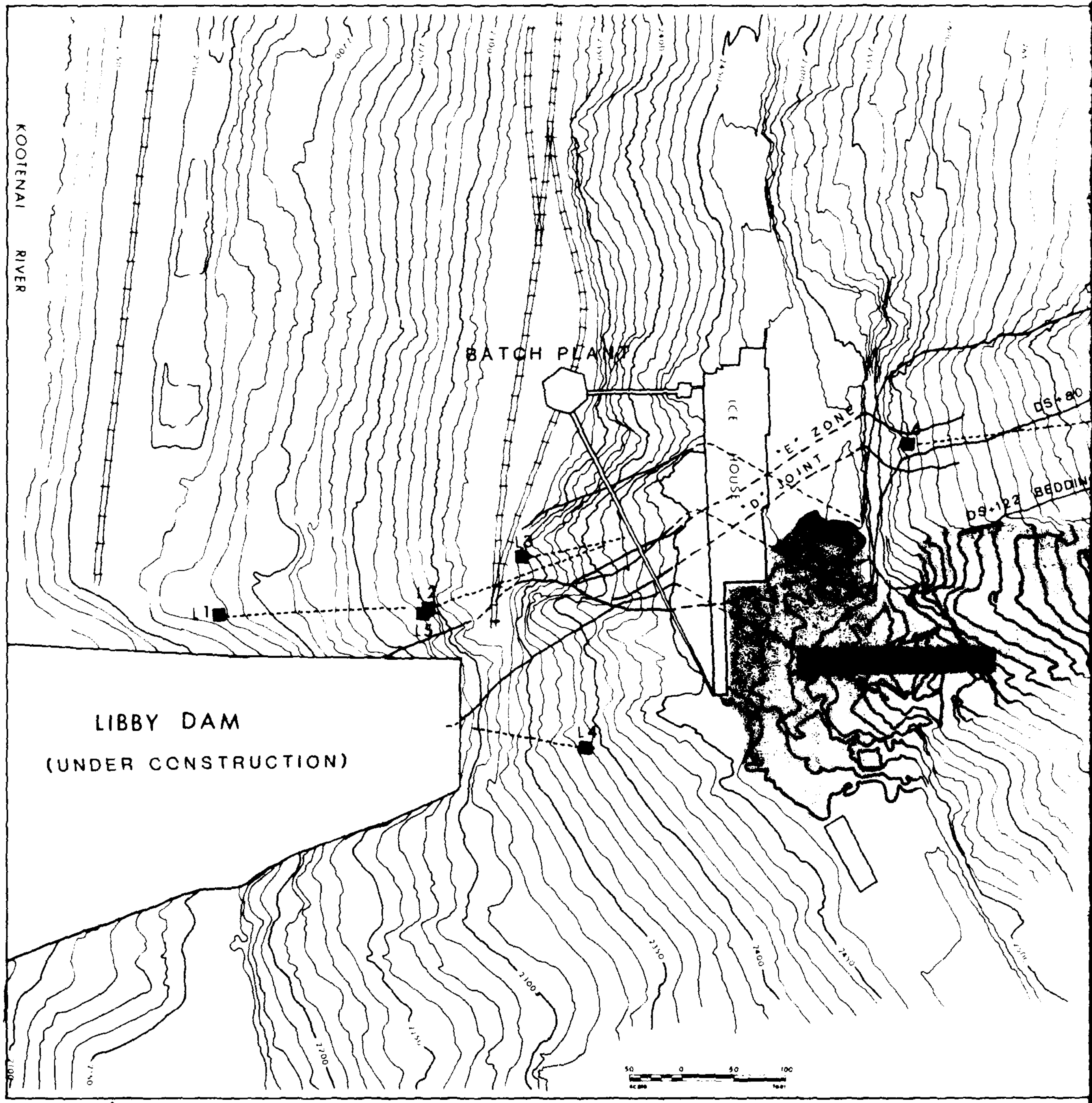


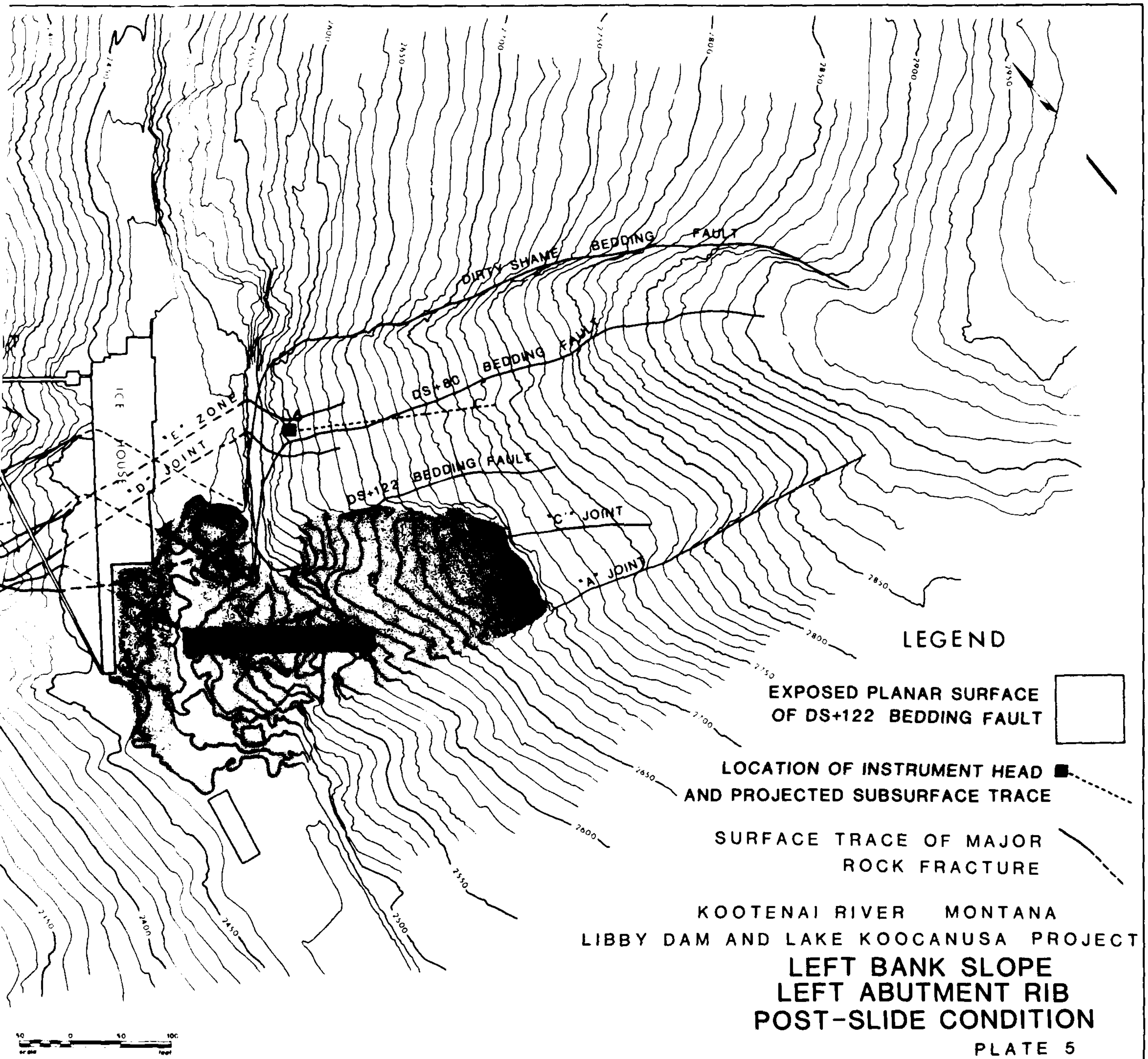
KOOTENAI RIVER MONTANA

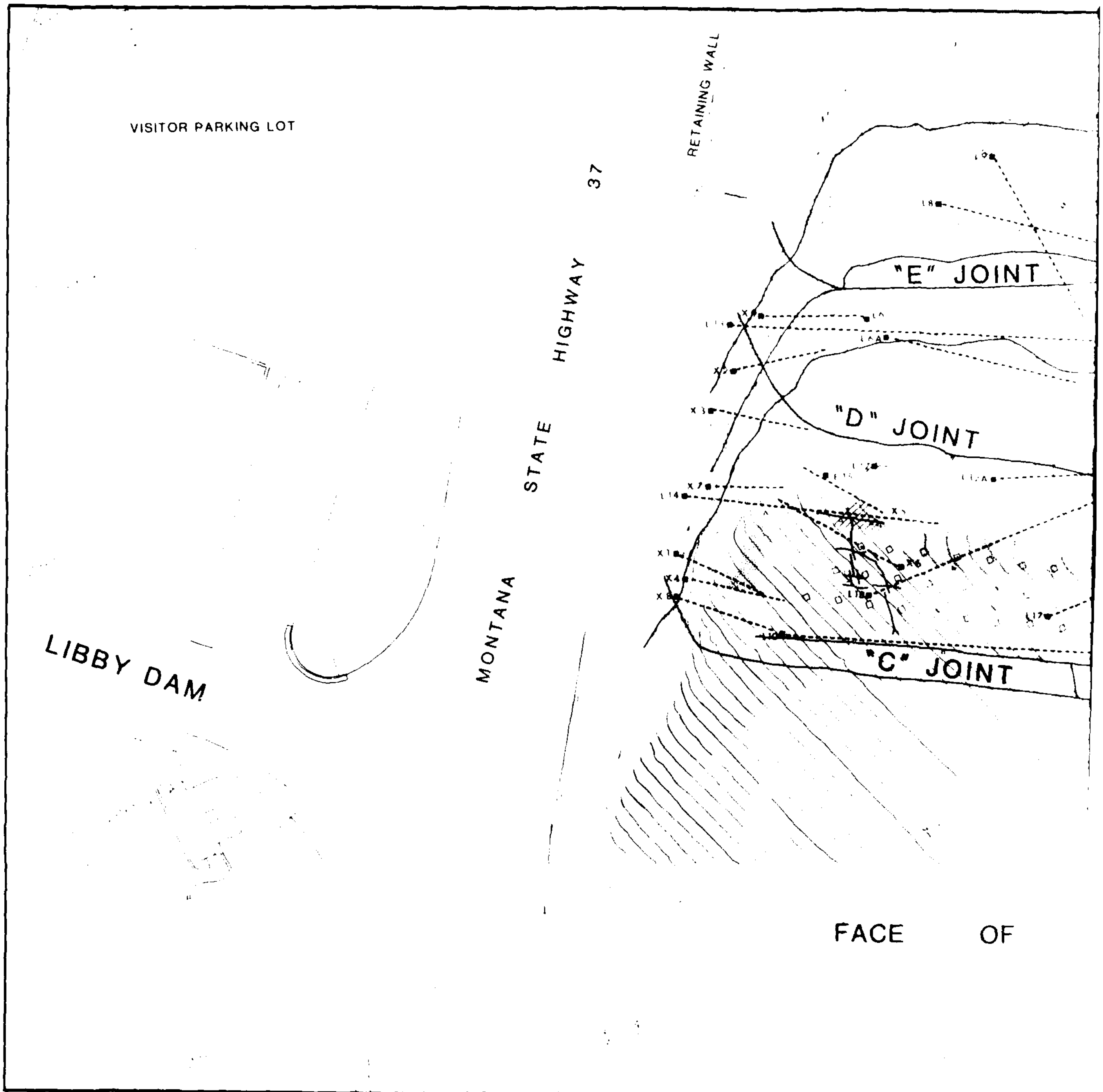
LIBBY DAM AND LAKE KOOCANUSA PROJECT

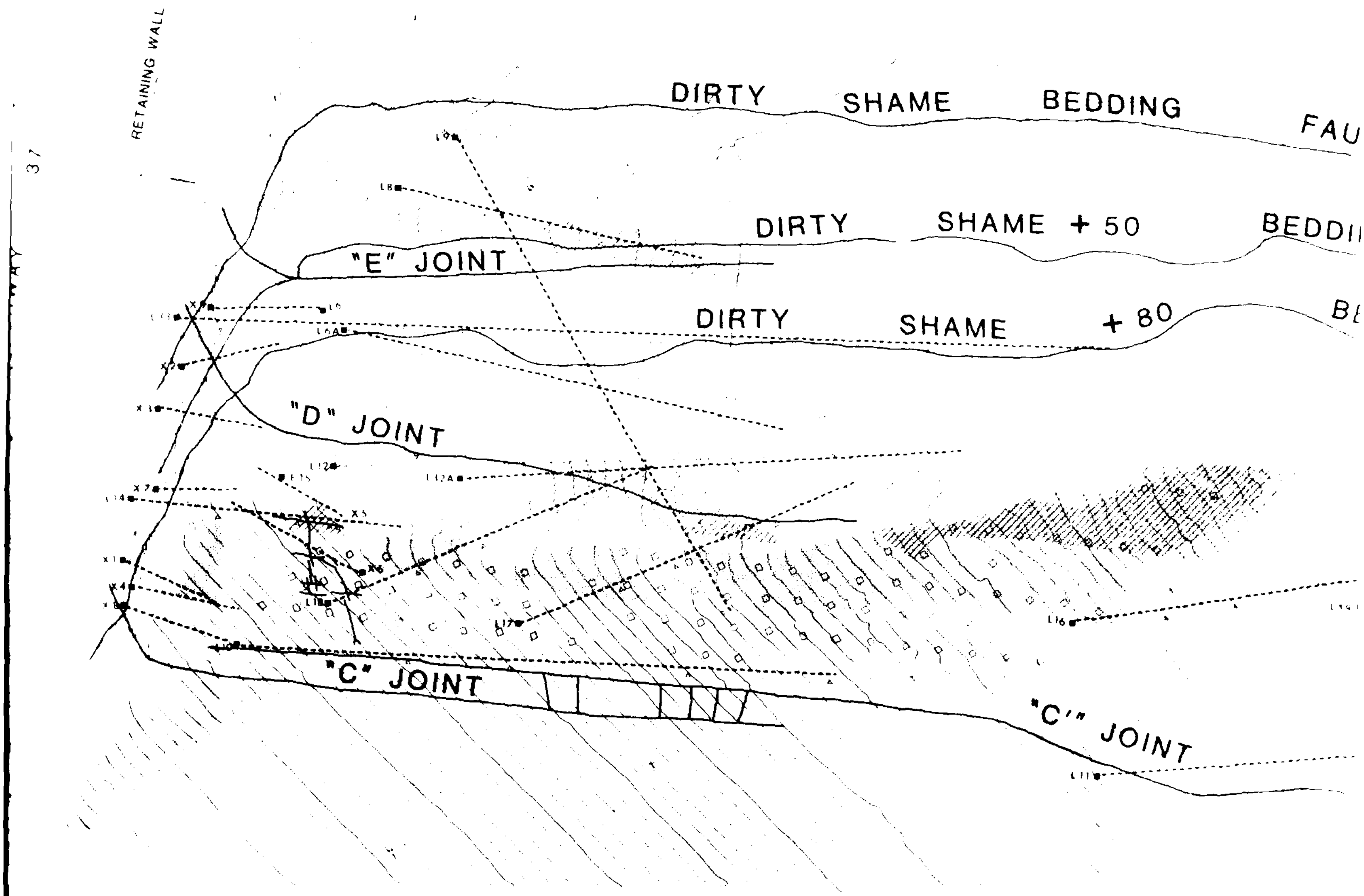
LEFT BANK SLOPE
LEFT ABUTMENT RIB
PRE-SLIDE CONDITION

PLATE 4

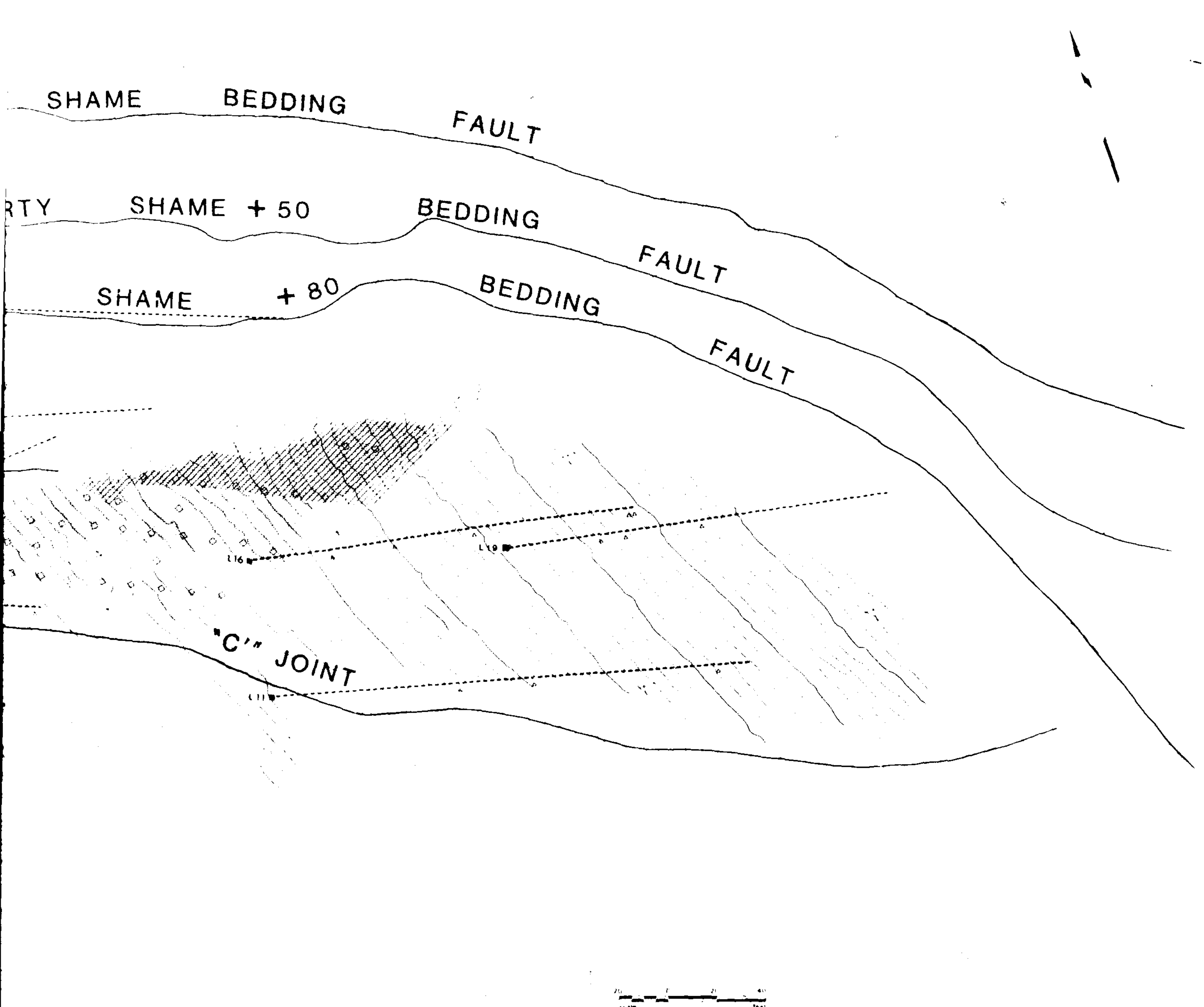

KOOTENAI RIVER
BATCH PLANT
ICE HOUSE
'E' ZONE
'D' JOINT
DS+80
DS+122 BEDDIN
L1
L2
L3
L4
L5
LIBBY DAM
(UNDER CONSTRUCTION)
2400

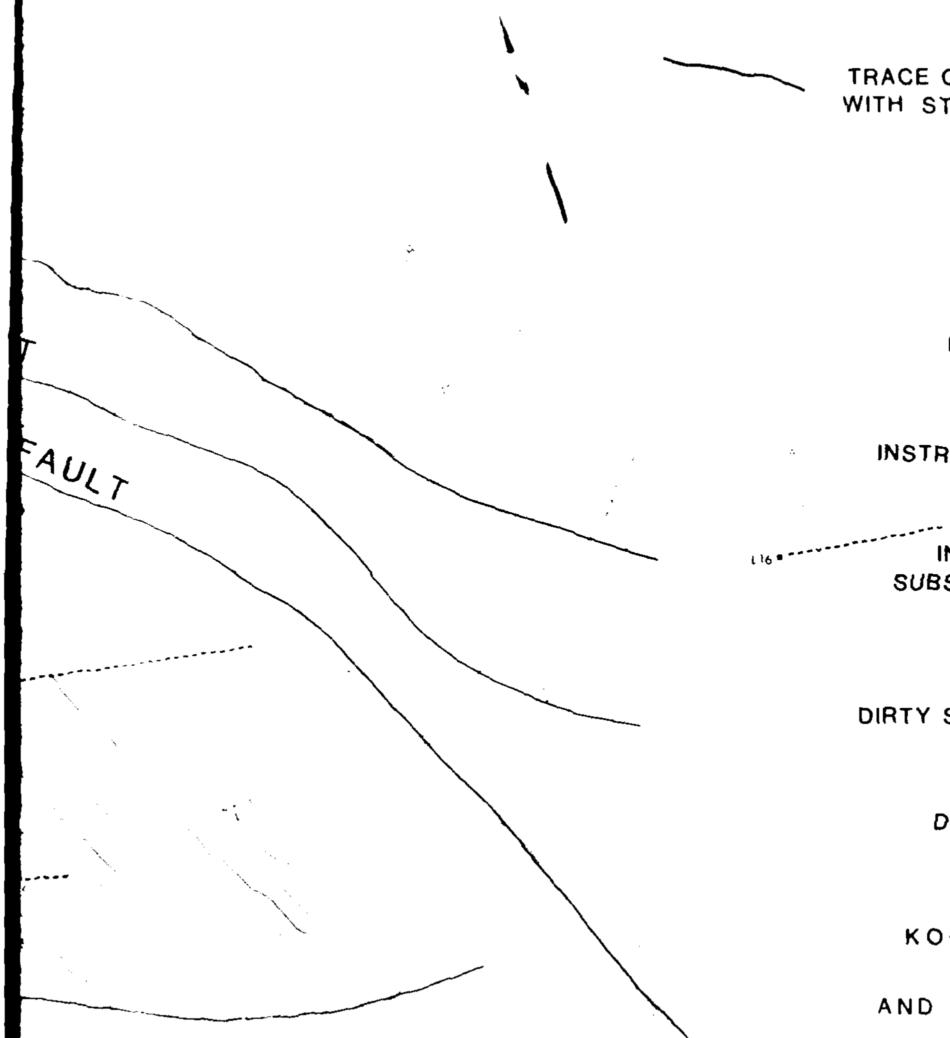

DIRTY SHAME BEDDING FAULT
DS+80 BEDDING FAULT
DS+122 BEDDING FAULT
"E" ZONE
"D" JOINT
ICE HOUSE
"C" JOINT
"A" JOINT
2850
2800
2750
2700
2650
2600
2550
2500
2450
2400
LEGEND
EXPOSED PLANAR SURFACE OF DS+122 BEDDING FAULT
LOCATION OF INSTRUMENT HEAD AND PROJECTED SUBSURFACE TRACE
SURFACE TRACE OF MAJOR ROCK FRACTURE
KOOTENAI RIVER MONTANA
LIBBY DAM AND LAKE KOOCANUSA PROJECT
LEFT BANK SLOPE
LEFT ABUTMENT RIB
POST-SLIDE CONDITION
PLATE 5


VISITOR PARKING LOT
RETAINING WALL
37
HIGHWAY
STATE
MONTANA
LIBBY DAM
"E" JOINT
"D" JOINT
"C" JOINT
FACE OF



FACE OF "A" JOINT


SHAME BEDDING FAULT
RTY SHAME + 50 BEDDING FAULT
SHAME + 80 BEDDING FAULT
L16
L19
"C'" JOINT
L11



LEGEND

TRACE OF MAJOR FRACTURES
WITH STRUCTURE CONTOURS

EXPOSED SURFACE OF
DIRTY SHAME + 122
BEDDING FAULT

INSTRUMENT ANCHOR POINT

TENDON HEADS

INSTRUMENT HEAD AND
SUBSURFACE PROJECTION
OF HOLE

REGION BOUNDED BY
TENDONS CROSSING
DIRTY SHAME BEDDING FAULT

REGION BOUNDED BY
TENDONS CROSSING
DS + 80 BEDDING FAULT

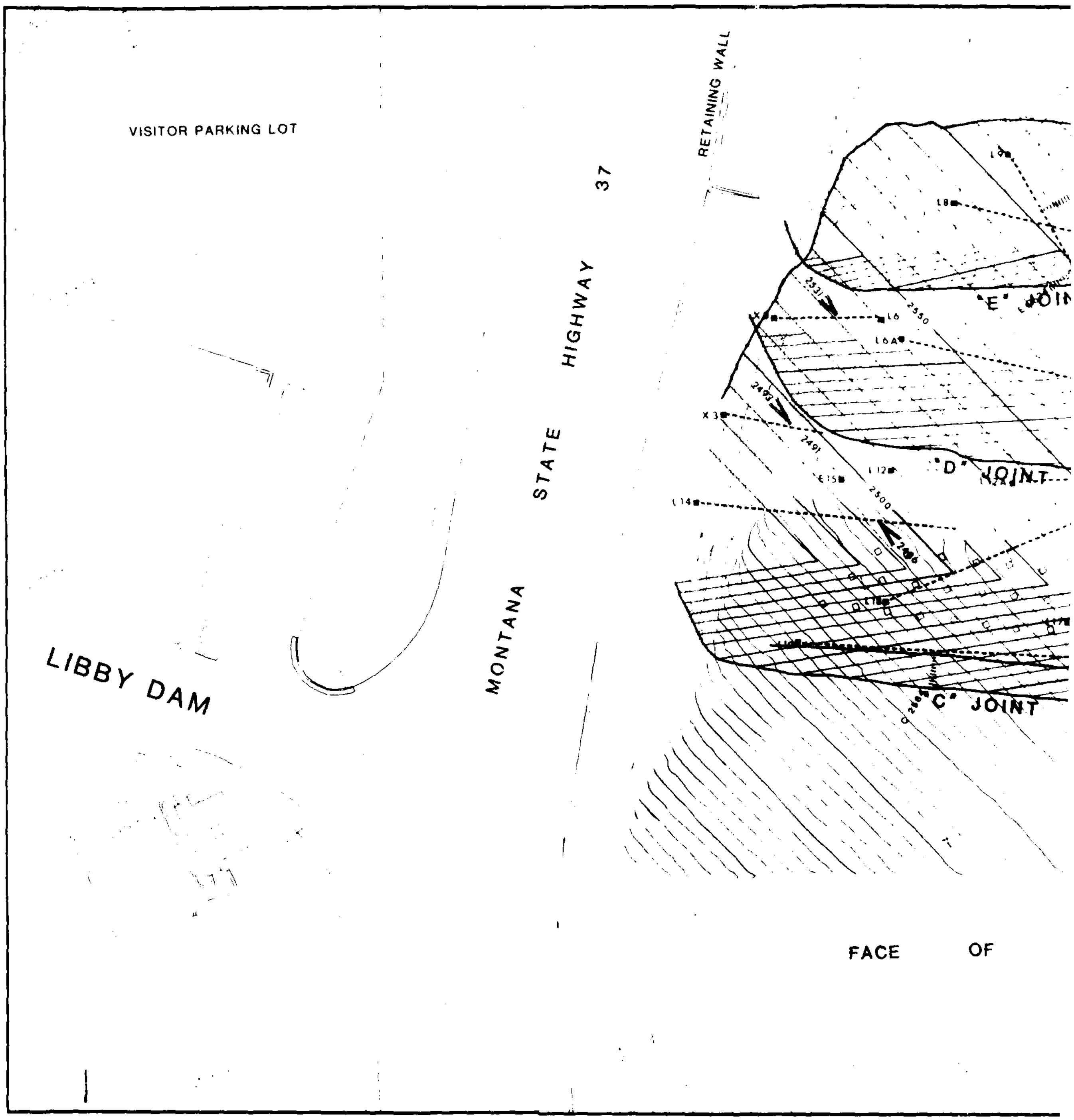
KOOTENAI RIVER MONTANA
LIBBY DAM
AND LAKE KOOCANUSA PROJECT

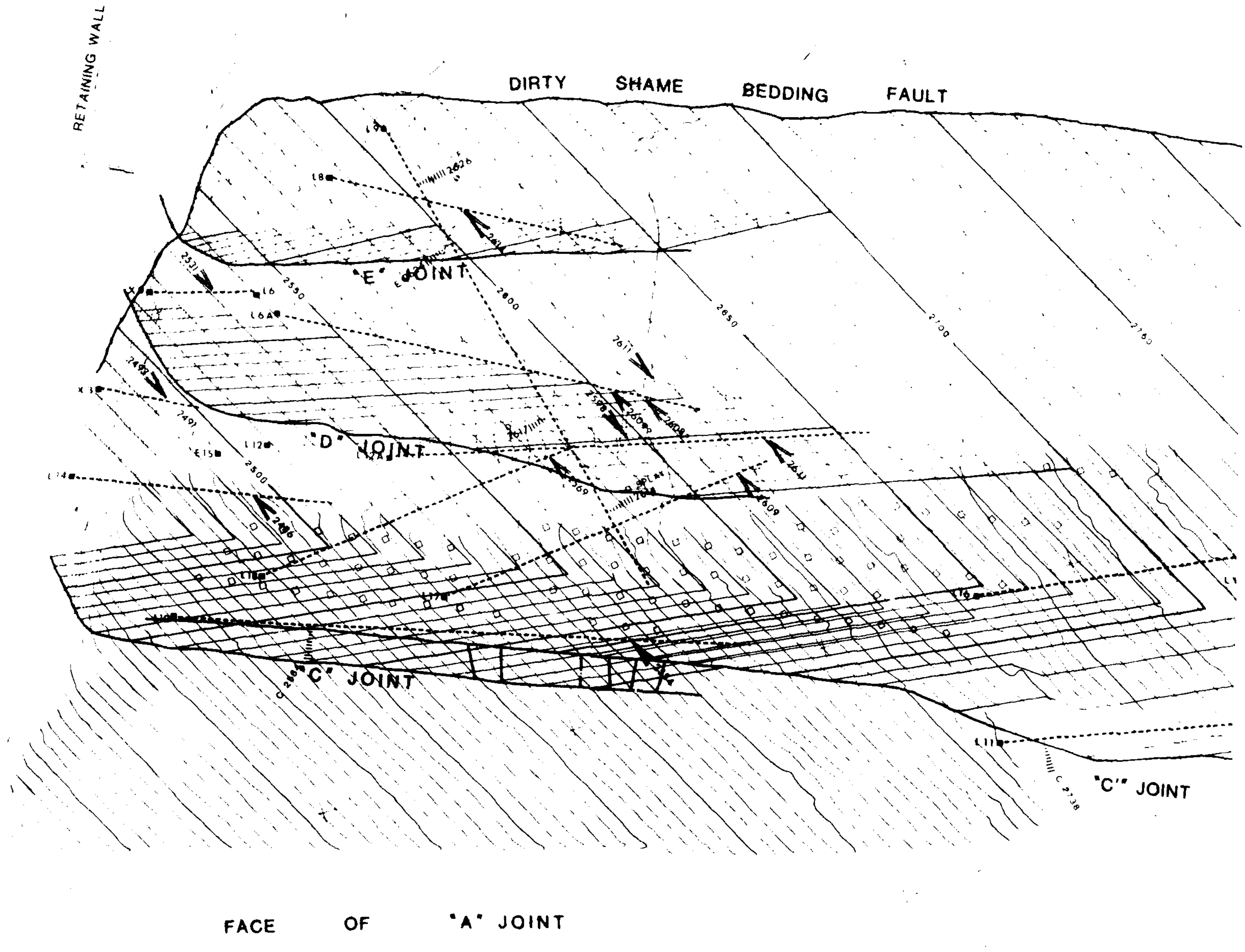
LEFT BANK SLOPE

LEFT ABUTMENT RIB

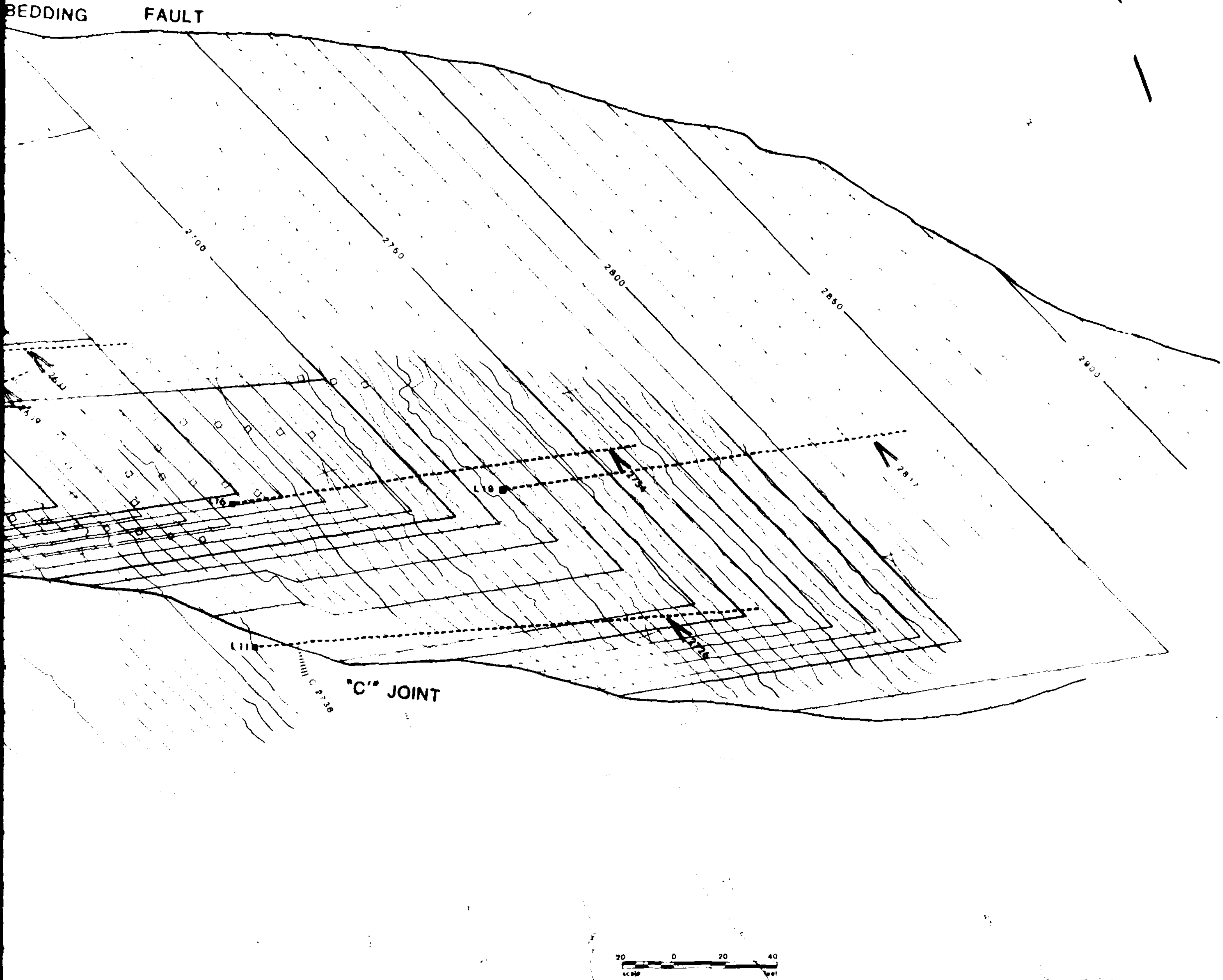
INSTRUMENT PLAN WITH GEOLOGY

PLATE 6


VISITOR PARKING LOT
RETAINING WALL
MONTANA STATE HIGHWAY 37
LIBBY DAM
"E" JOINT
"D" JOINT
"C" JOINT
FACE OF

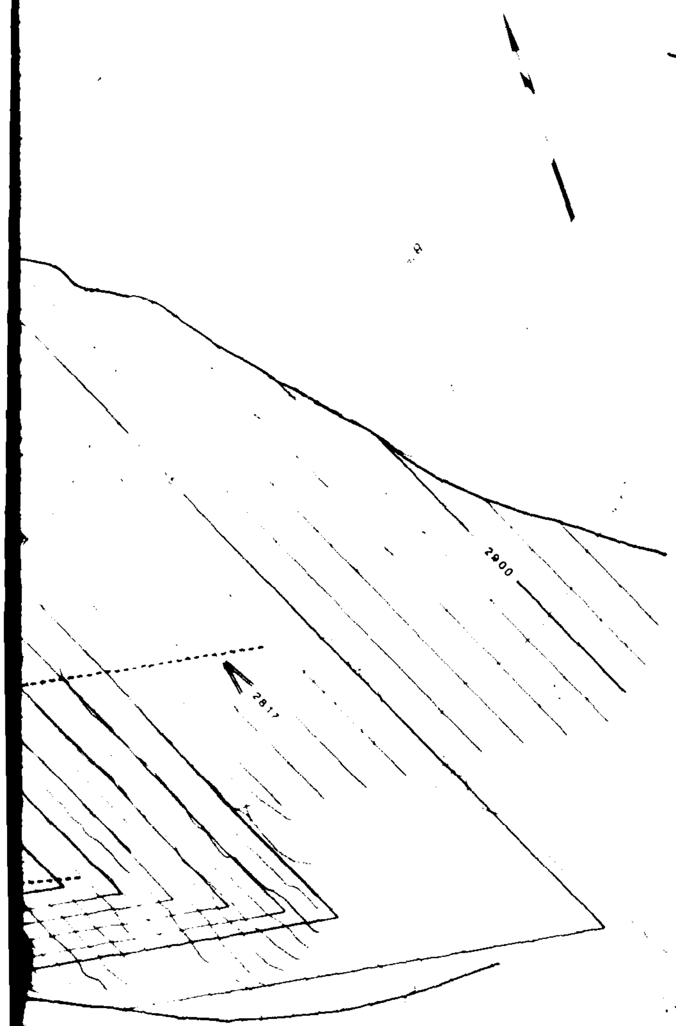


RETAINING WALL
DIRTY SHAME BEDDING FAULT
"E" JOINT
"D" JOINT
"C" JOINT
"C'" JOINT
FACE OF "A" JOINT



BEDDING
FAULT
2700
2750
2800
2850
2900
L19
L11
"C" JOINT
scale
feet
20
0
20
40

13



LEGEND

TRACE OF MAJOR FRACTURES WITH STRUCTURE CONTOURS

2650 HOLE INTERSECTS DIRTY SHAME BEDDING FAULT

2614 HOLE INTERSECTS MAJOR JOINT

EXPOSED SURFACE OF DIRTY SHAME + 122 BEDDING FAULT

INSTRUMENT ANCHOR POINT

TENDON HEADS

L16 INSTRUMENT HEAD AND SUBSURFACE PROJECTION OF HOLE

REGION BOUNDED BY TENDONS CROSSING DIRTY SHAME BEDDING FAULT

REGION BOUNDED BY TENDONS CROSSING DS + 80 BEDDING FAULT

KOOTENAI RIVER MONTANA

LIBBY DAM

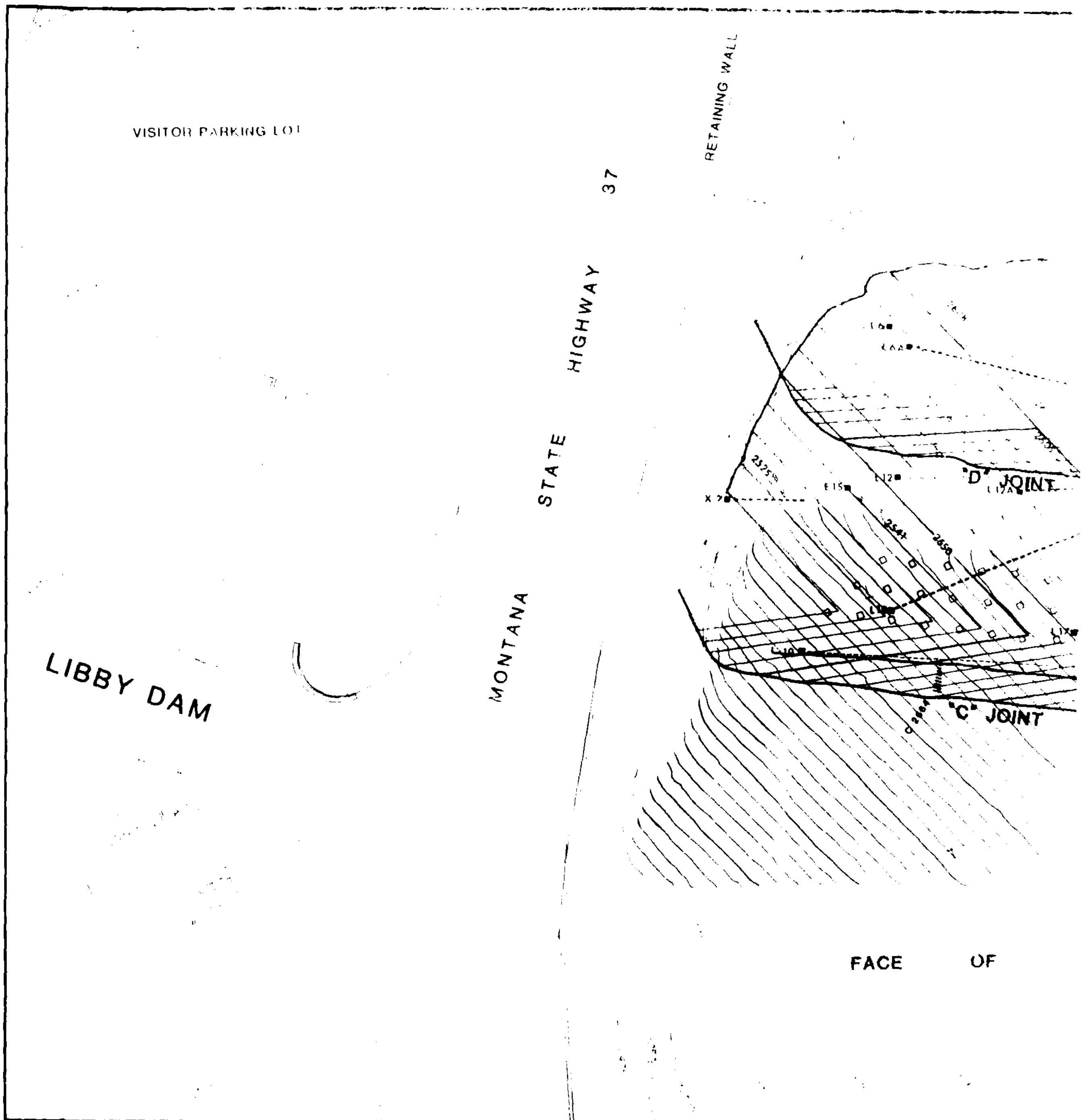
AND LAKE KOOCANUSA PROJECT

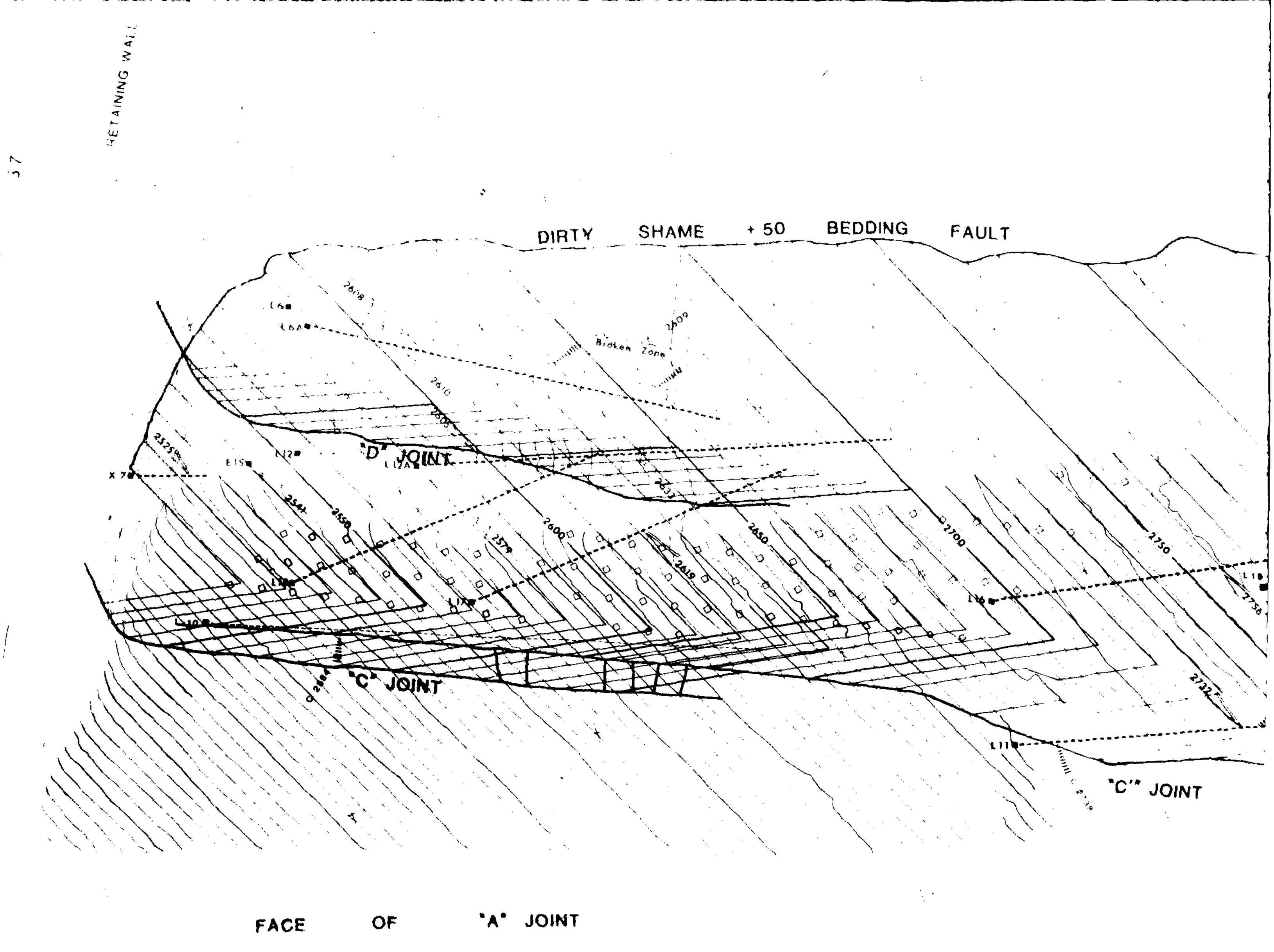
LEFT BANK SLOPE
LEFT ABUTMENT RIB

DIRTY SHAME/C-C' BLOCK AND ASSOCIATED BLOCKS

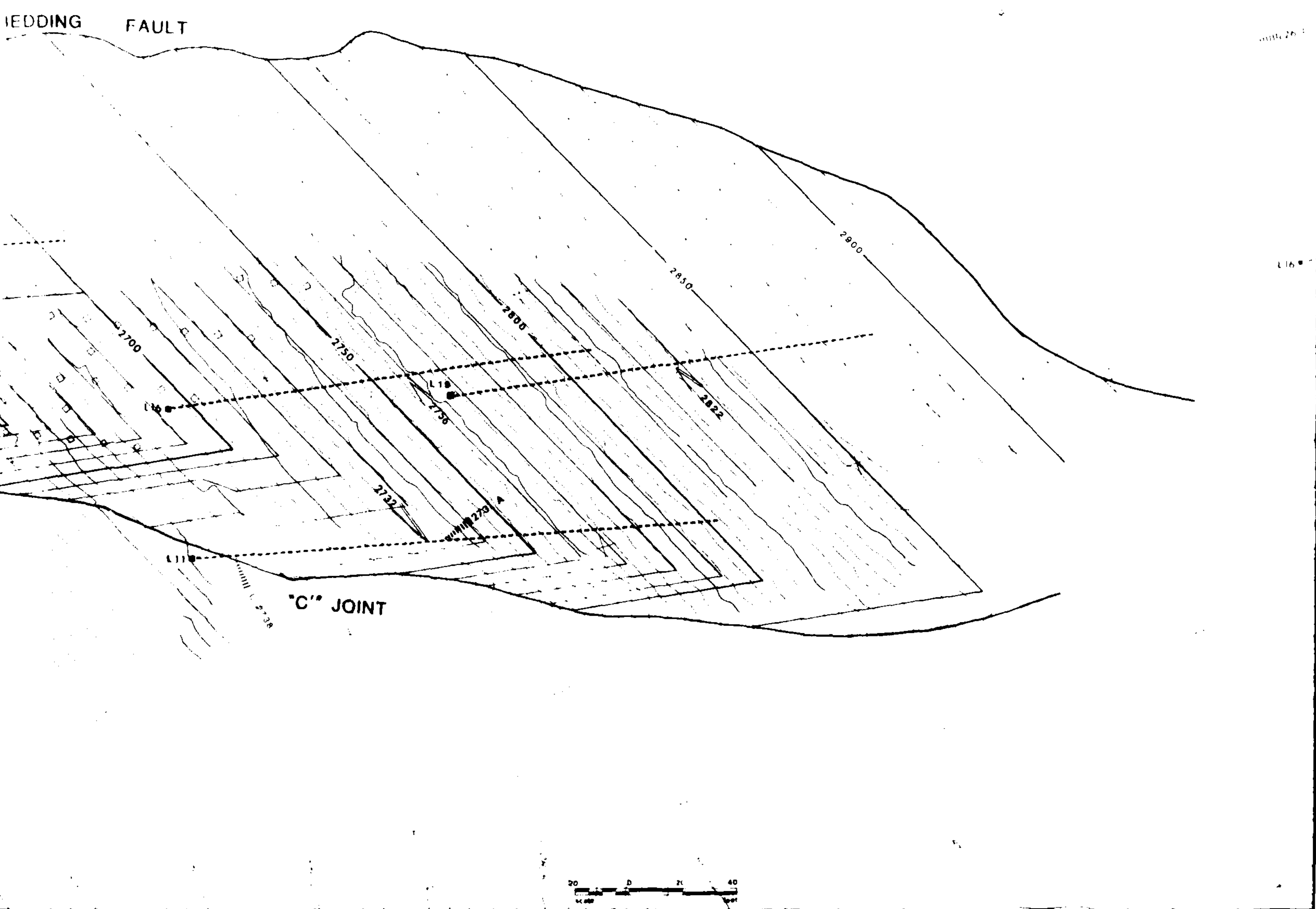
PLATE 7

4

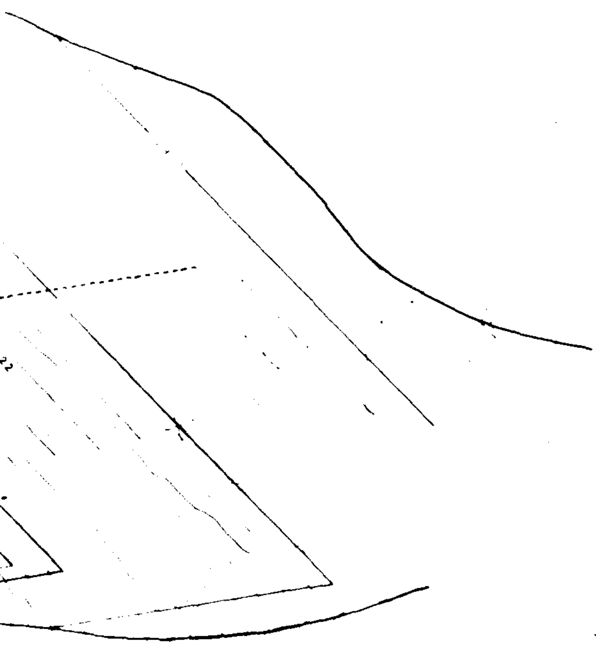

VISITOR PARKING LOT
RETAINING WALL
MONTANA STATE HIGHWAY 37
LIBBY DAM
"D" JOINT
"C" JOINT
FACE OF



RETAINING WALL
DIRTY SHAME +50 BEDDING FAULT
Broken Zone
"D" JOINT
"C" JOINT
"C'" JOINT
2550
2600
2650
2700
2750
FACE OF "A" JOINT



BEDDING FAULT
"C" JOINT
2700
2750
2800
2850
2900
2732
2736
2822



LEGEND

TRACE OF MAJOR FRACTURES WITH STRUCTURE CONTOURS

HOLE INTERSECTS DS + 50 BEDDING FAULT

HOLE INTERSECTS MAJOR JOINT

EXPOSED SURFACE OF DIRTY SHAME + 122 BEDDING FAULT

INSTRUMENT ANCHOR POINT

TENDON HEADS

INSTRUMENT HEAD AND SUBSURFACE PROJECTION OF HOLE

REGION BOUNDED BY TENDONS CROSSING DIRTY SHAME BEDDING FAULT

REGION BOUNDED BY TENDONS CROSSING DS + 80 BEDDING FAULT

KOOTENAI RIVER MONTANA

LIBBY DAM

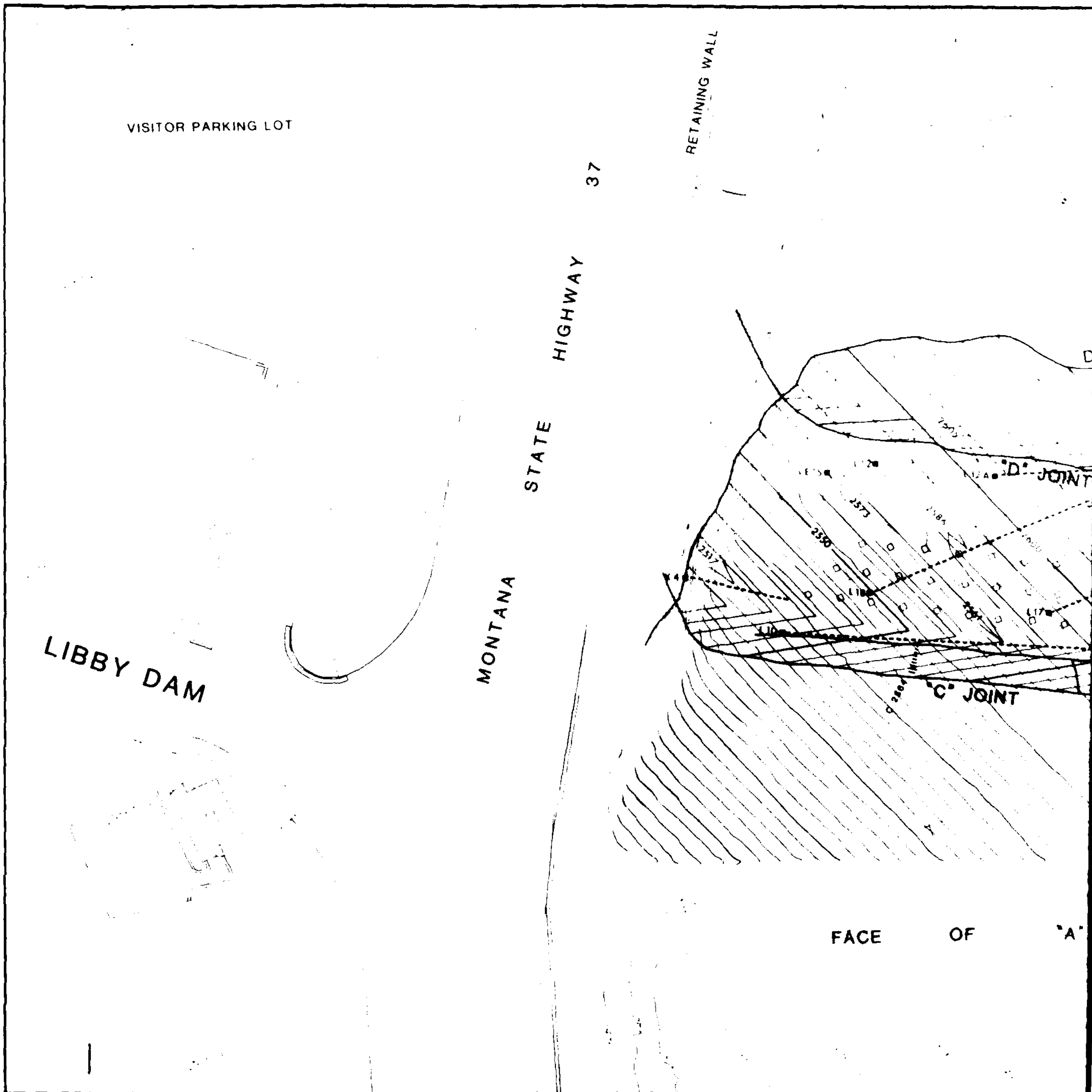
AND LAKE KOOCANUSA PROJECT

LEFT BANK SLOPE

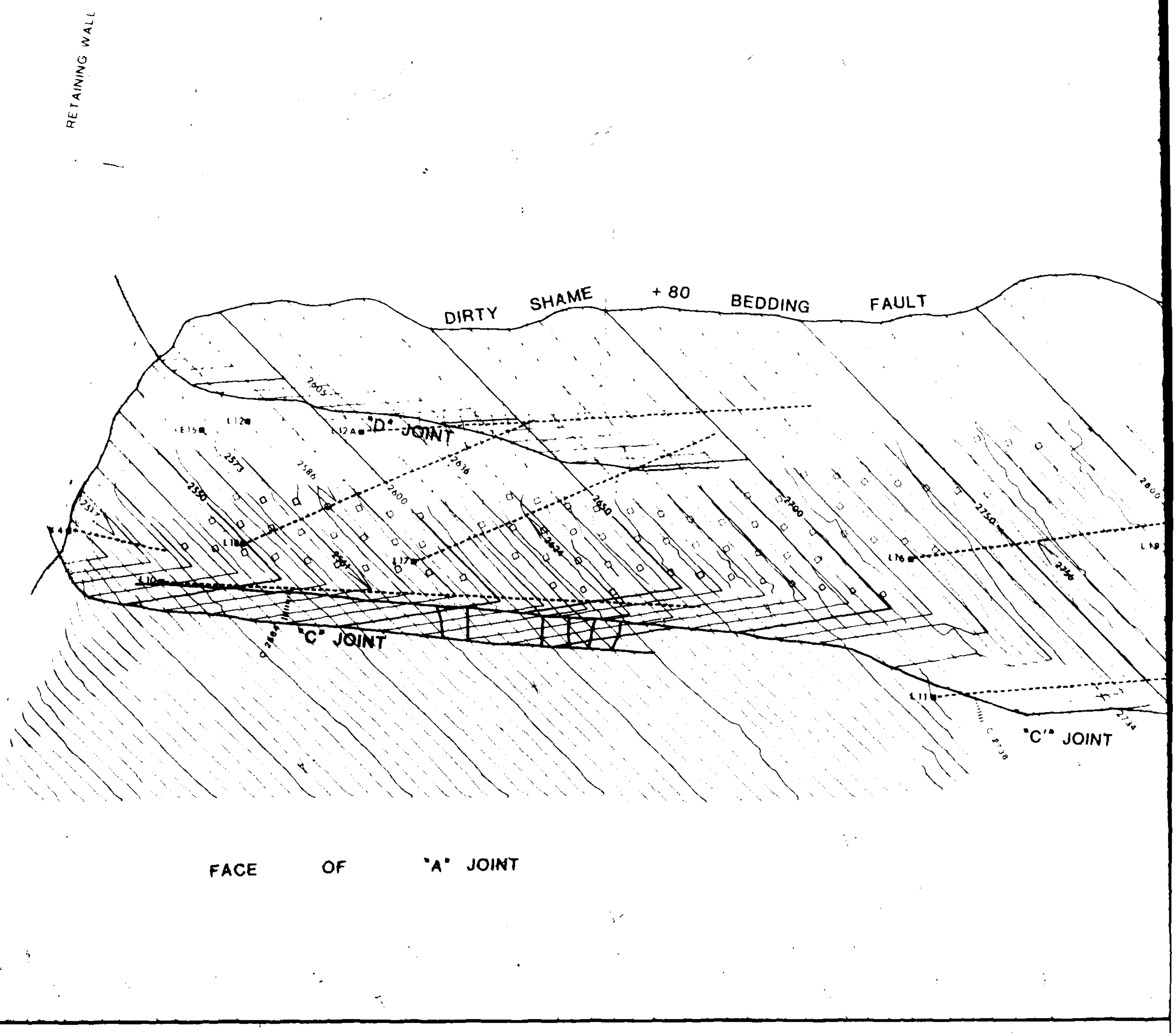
LEFT ABUTMENT RIB

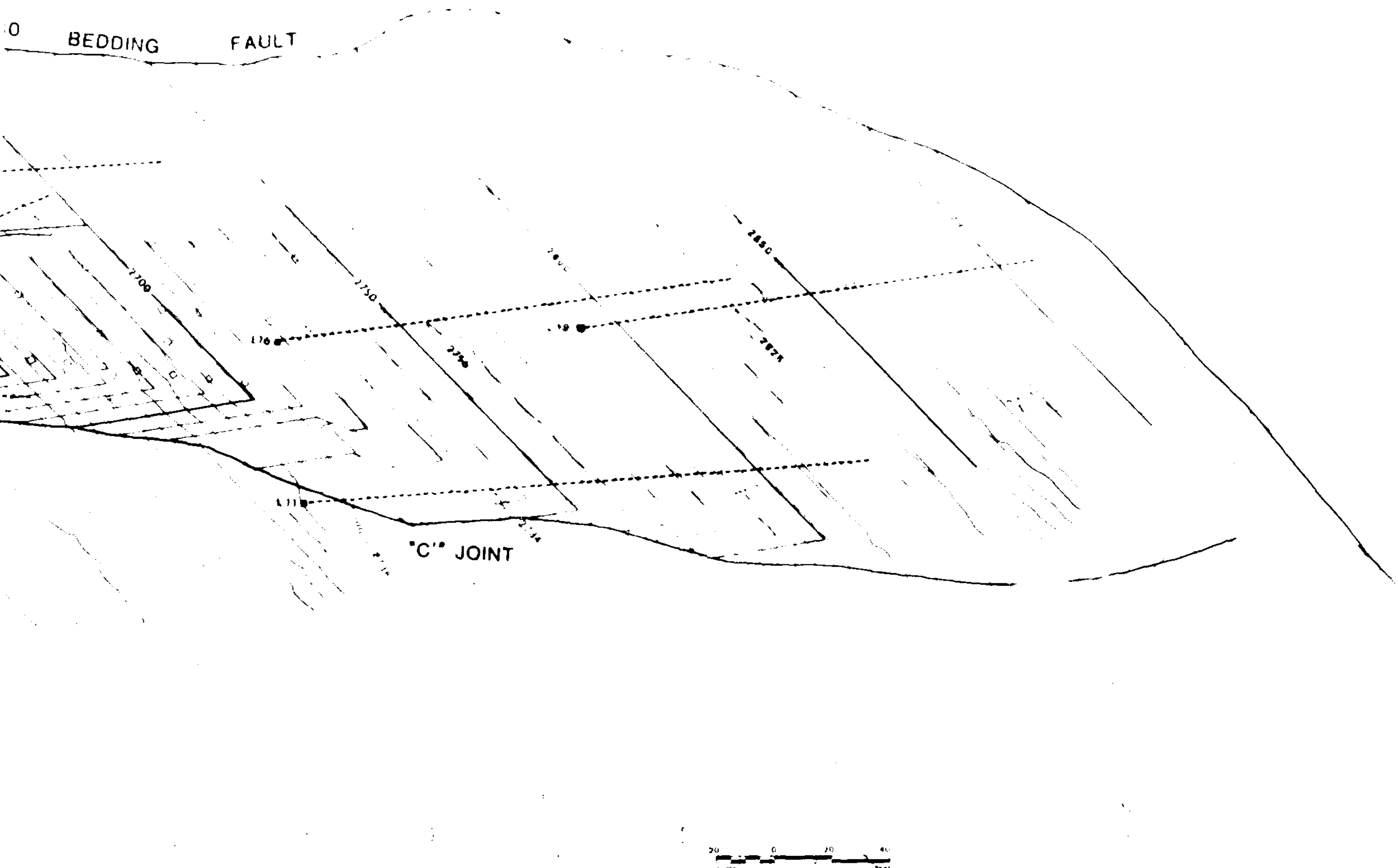
DIRTY SHAME+50/C-C' BLOCK AND ASSOCIATED BLOCKS

PLATE 8

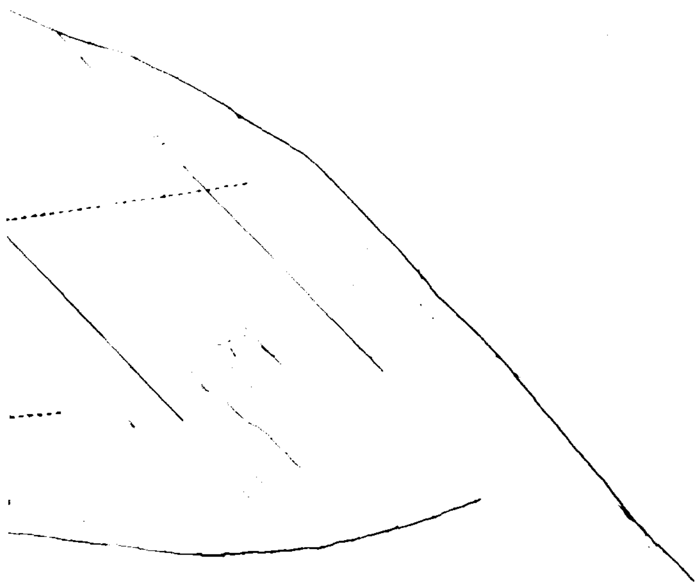


VISITOR PARKING LOT
RETAINING WALL
MONTANA STATE HIGHWAY 37
LIBBY DAM
"D" JOINT
"C" JOINT
FACE OF "A"


RETAINING WALL
DIRTY SHAME +80 BEDDING FAULT
"D" JOINT
"C" JOINT
"C'" JOINT
FACE OF "A" JOINT



3



LEGEND

TRACE OF MAJOR FRACTURES WITH STRUCTURE CONTOURS

HOLE INTERSECTS DS + 80 BEDDING FAULT

HOLE INTERSECTS MAJOR JOINT

EXPOSED SURFACE OF DIRTY SHAME + 122 BEDDING FAULT

INSTRUMENT ANCHOR POINT

TENDON HEADS

INSTRUMENT HEAD AND SUBSURFACE PROJECTION OF HOLE

REGION BOUNDED BY TENDONS CROSSING DIRTY SHAME BEDDING FAULT

REGION BOUNDED BY TENDONS CROSSING DS + 80 BEDDING FAULT

KOOTENAI RIVER MONTANA

LIBBY DAM

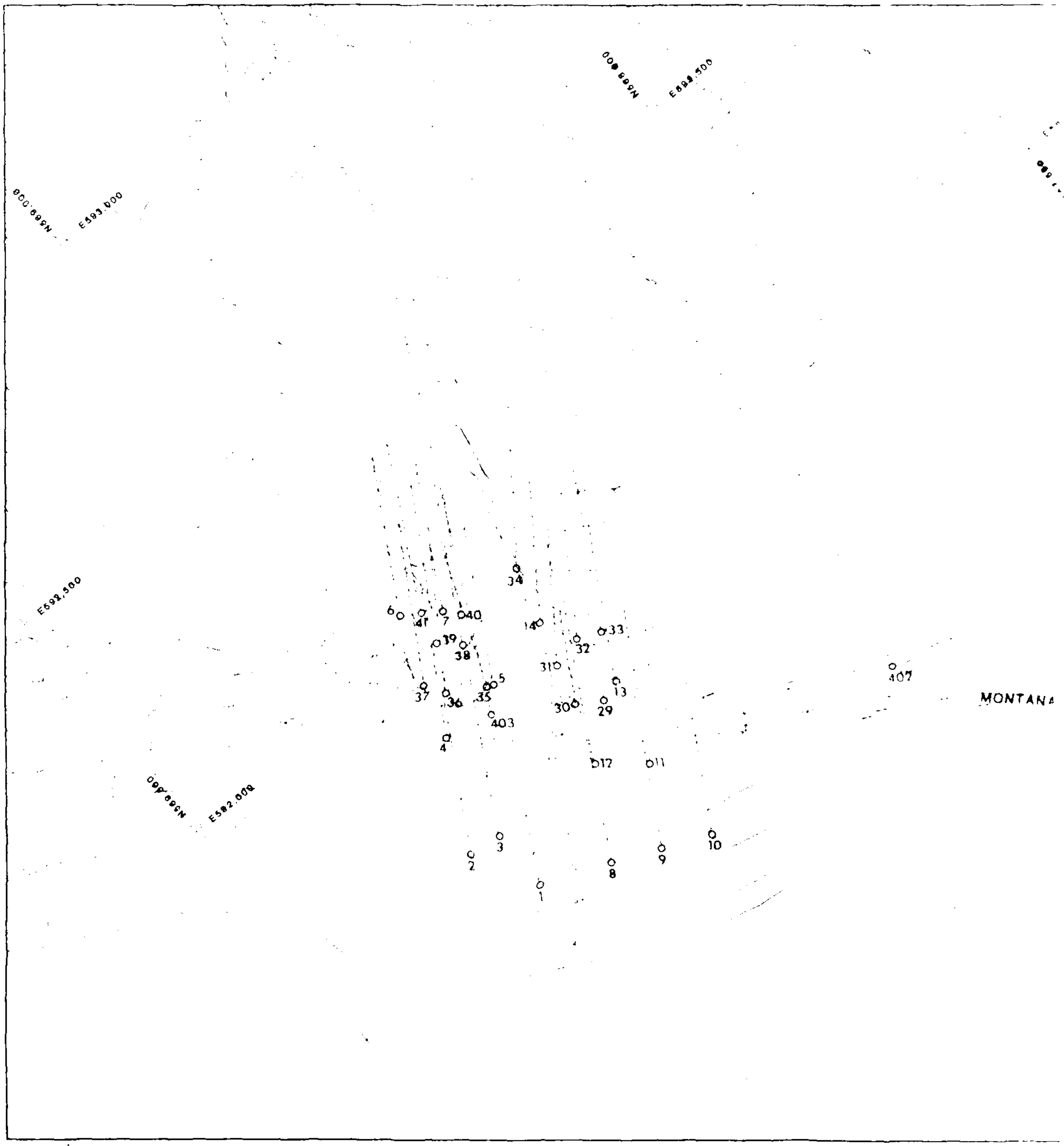
AND LAKE KOOCANUSA PROJECT

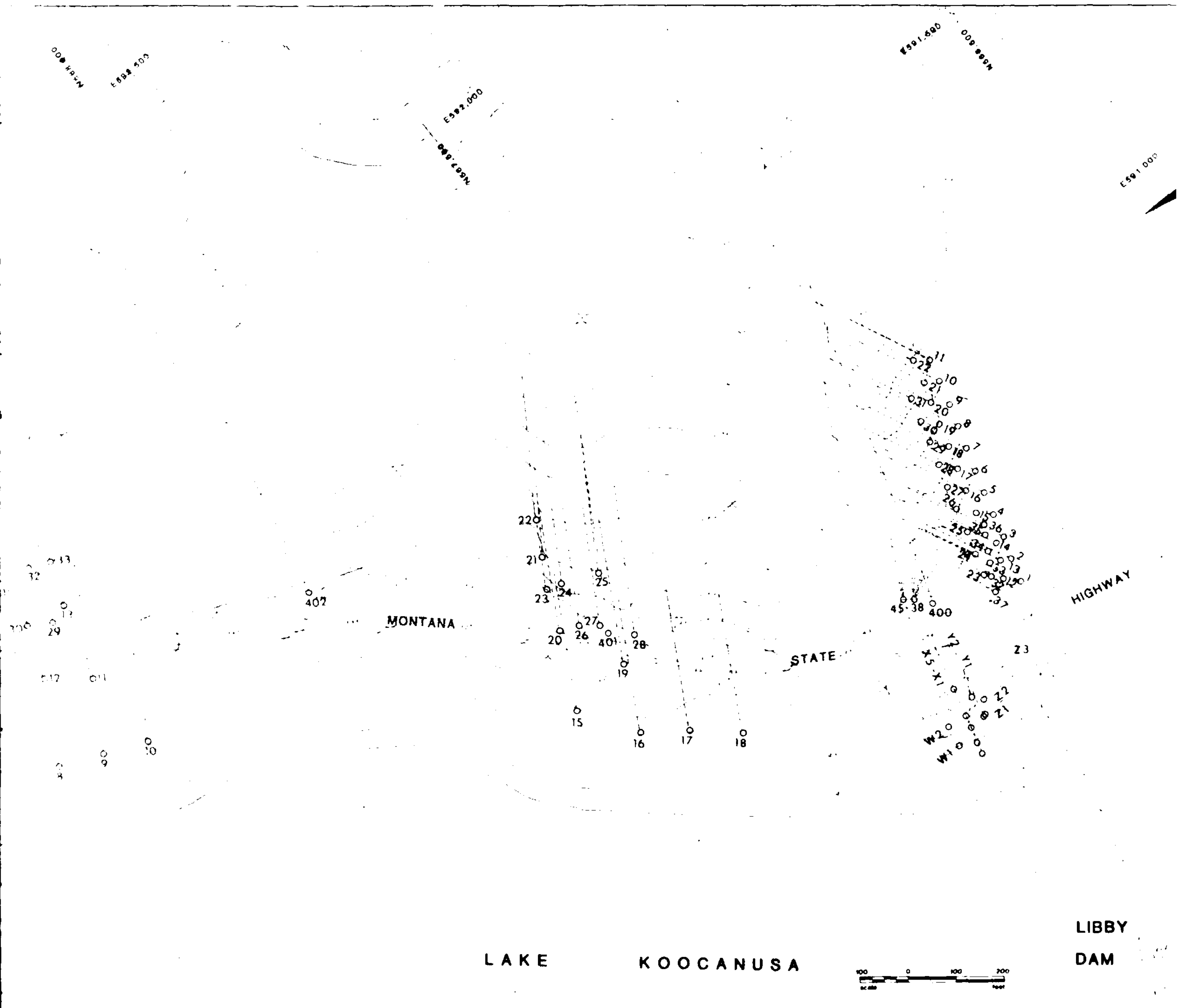
LEFT BANK SLOPE

LEFT ABUTMENT RIB

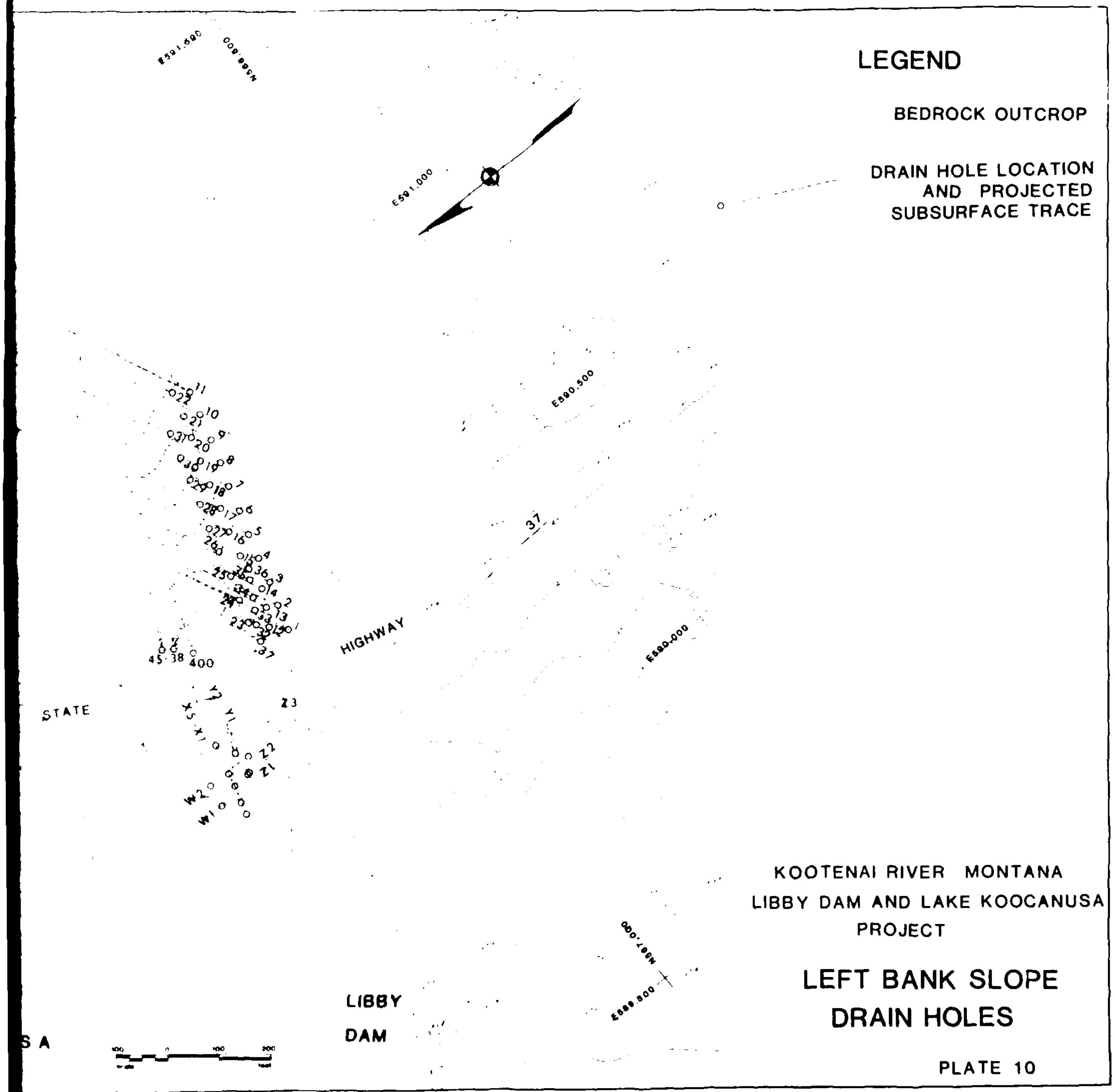
DIRTY SHAME+80/C-C' BLOCK AND ASSOCIATED BLOCKS

PLATE 9


E593,000
E593,500
E592,500
E592,000
MONTANA
34
6
41
7
40
14
33
32
19
38
31
5
37
36
35
13
30
29
403
4
12
11
407
3
2
10
9
8
1



MONTANA
STATE
HIGHWAY
LAKE KOOCANUSA
LIBBY
DAM
E592,000
E591,000


LEGEND
BEDROCK OUTCROP
DRAIN HOLE LOCATION AND PROJECTED SUBSURFACE TRACE
STATE
HIGHWAY
LIBBY
DAM
KOOTENAI RIVER MONTANA
LIBBY DAM AND LAKE KOOCANUSA PROJECT
LEFT BANK SLOPE
DRAIN HOLES
PLATE 10

END
DATE
FILMED
7 – 84
DTIC